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(54) DEVICES AND METHODS FOR ADJUSTING LENS POSITIONS BASED ON ENCODED LIGHT PATTERNS

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(Continued)

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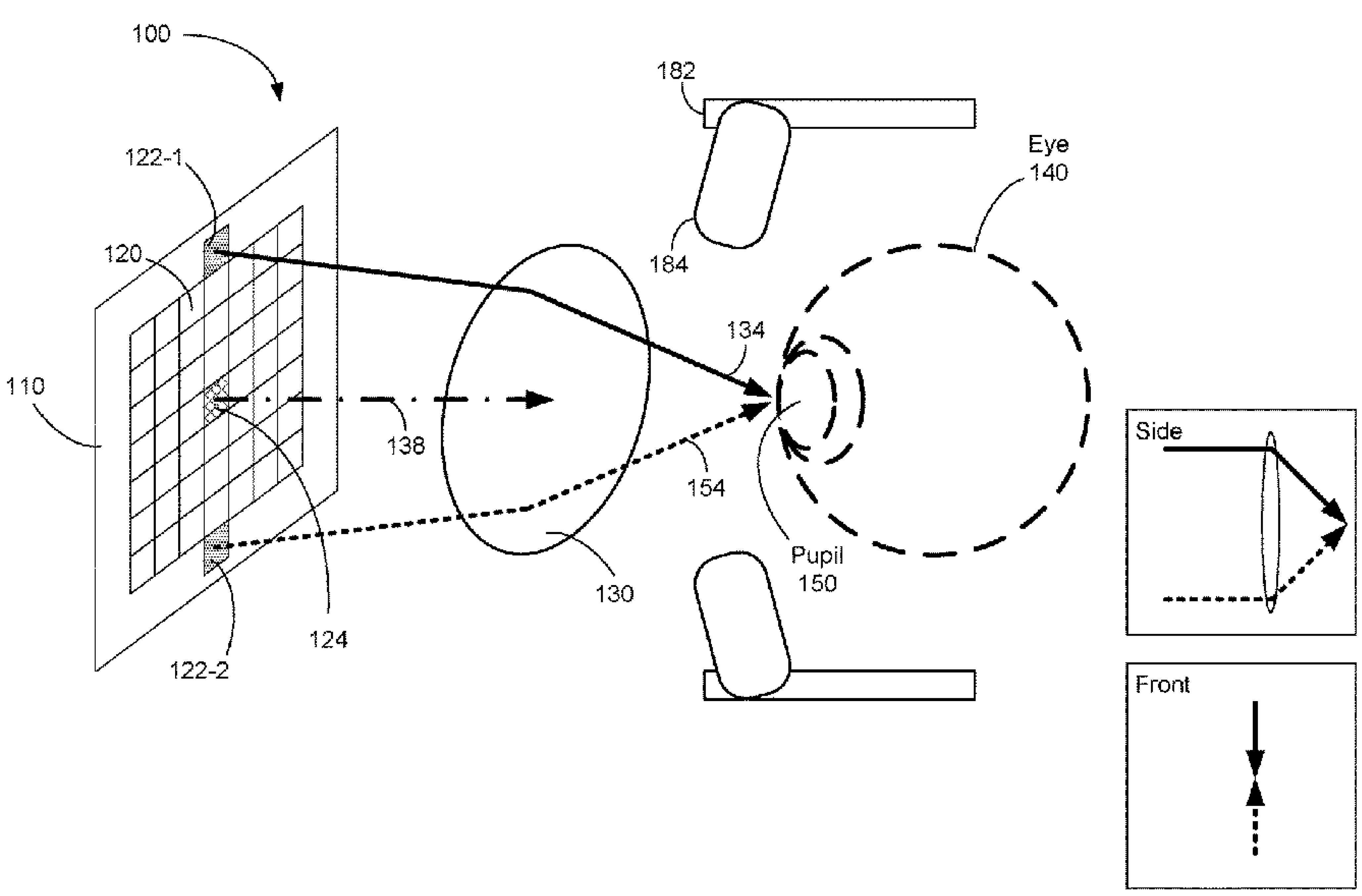
(57) ABSTRACT

A device includes a first light source device configured to transmit a first light in a first direction and a second light source device configured to transmit a second light in a second direction. The device also includes a first set of one or more lenses configured for directing the first light from the first light source device and the second light from the second light source device toward a first eye of a user. Also disclosed is a method that includes transmitting a first light and a second light through a first set of one or more lenses and directing the first light and the second light toward a first eye of a user. Further disclosed is a method for adjusting a distance between an eye and a lens of the first set of one or more lenses.

20 Claims, 18 Drawing Sheets



(51) **Int. Cl.**
G02B 27/42 (2006.01)
G06T 7/73 (2017.01)

(52) **U.S. Cl.**
CPC *G02B 2027/0159* (2013.01); *G06T 2207/10152* (2013.01); *G06T 2207/30201* (2013.01)

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USPC 351/204; 345/619, 629, 632, 633; 359/630–633
See application file for complete search history.

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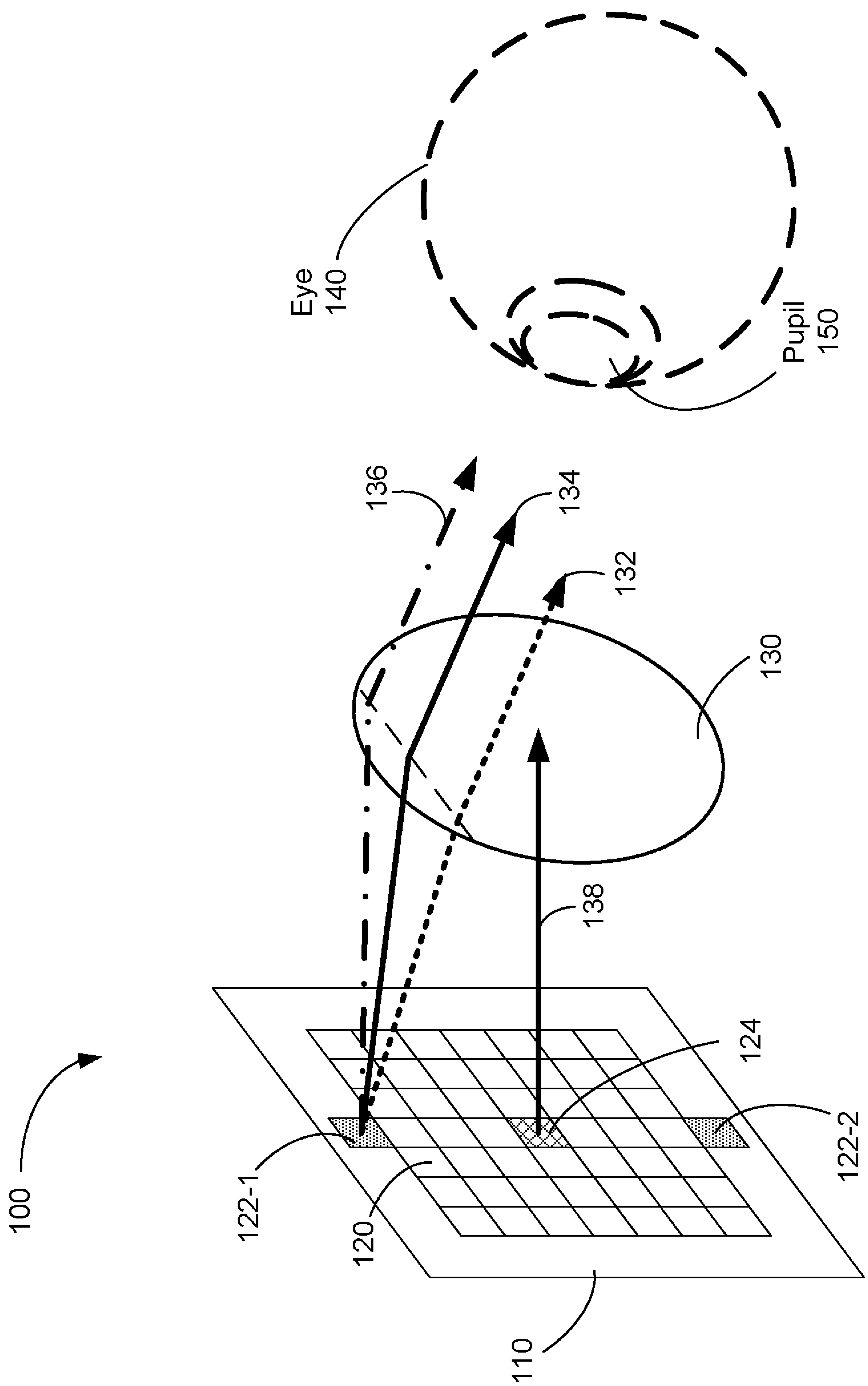
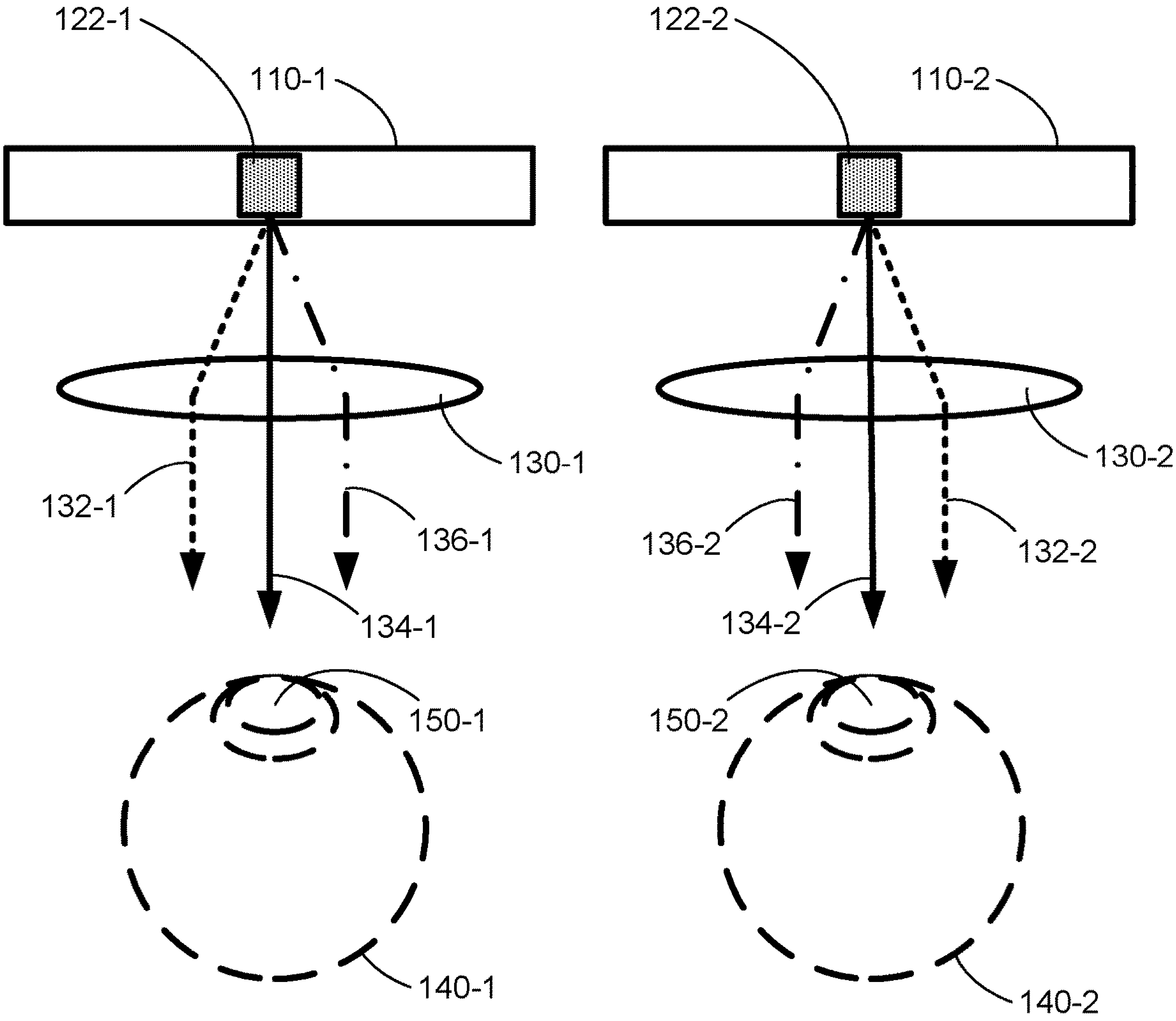


Figure 1A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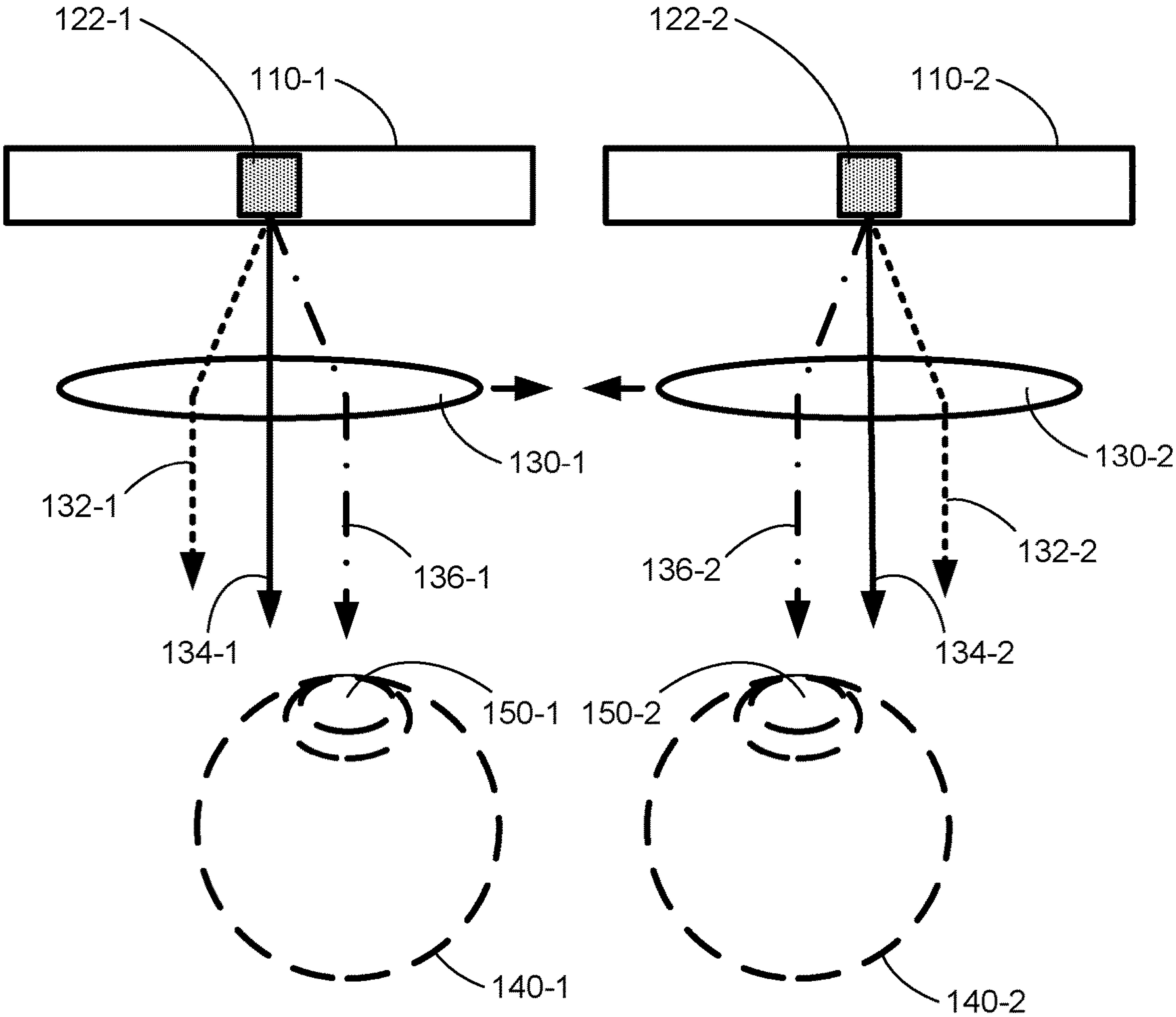
110-1
122-2
110-2
130-1
130-2
132-1
136-1
136-2
132-2
134-1
134-2
150-1
150-2
140-1
140-2

Figure 1B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110-1
122-2
110-2
130-1
130-2
132-1
136-1
136-2
132-2
134-1
134-2
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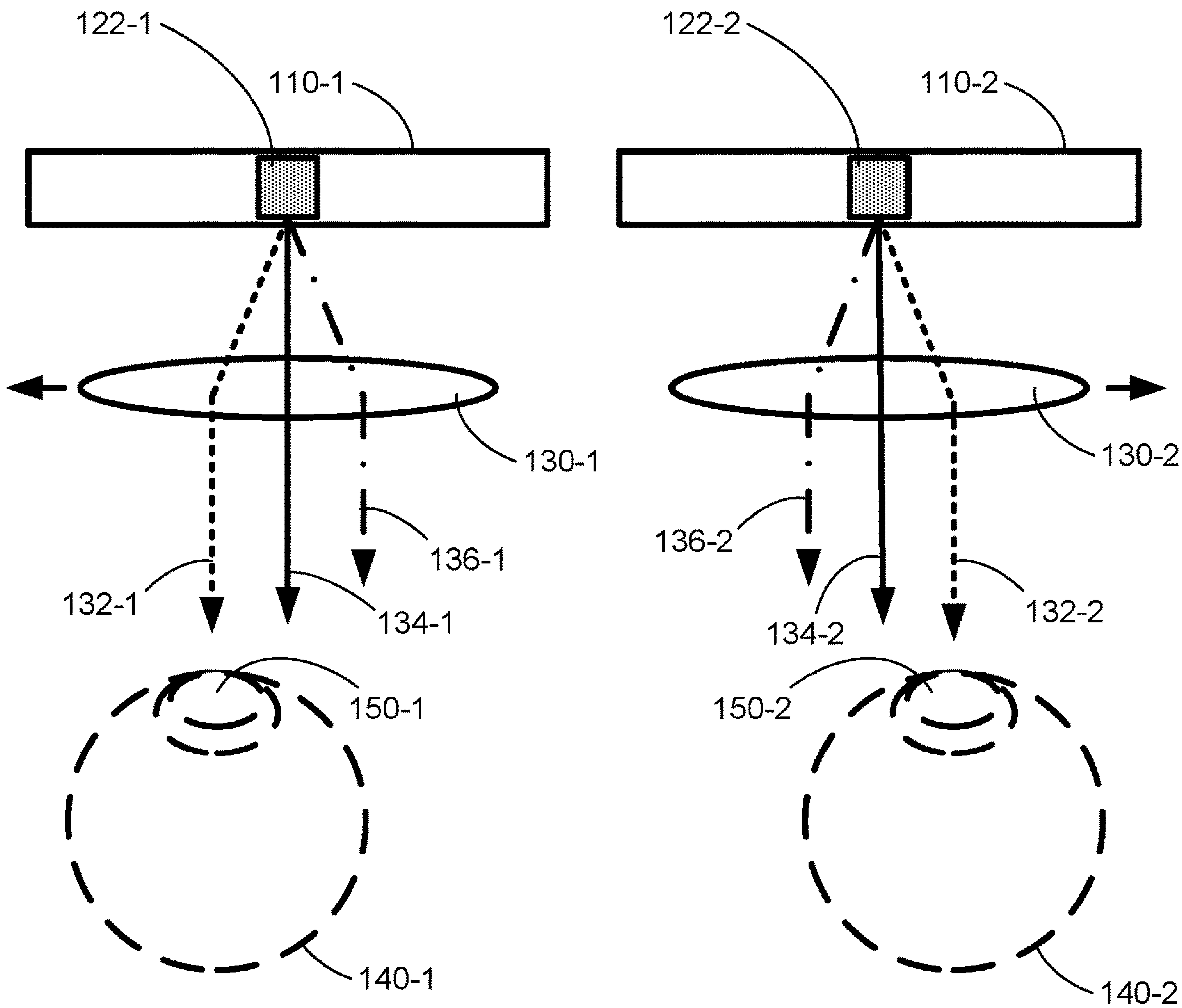
150-2
140-1
140-2

Figure 1C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122-2
110-2
130-1
130-2
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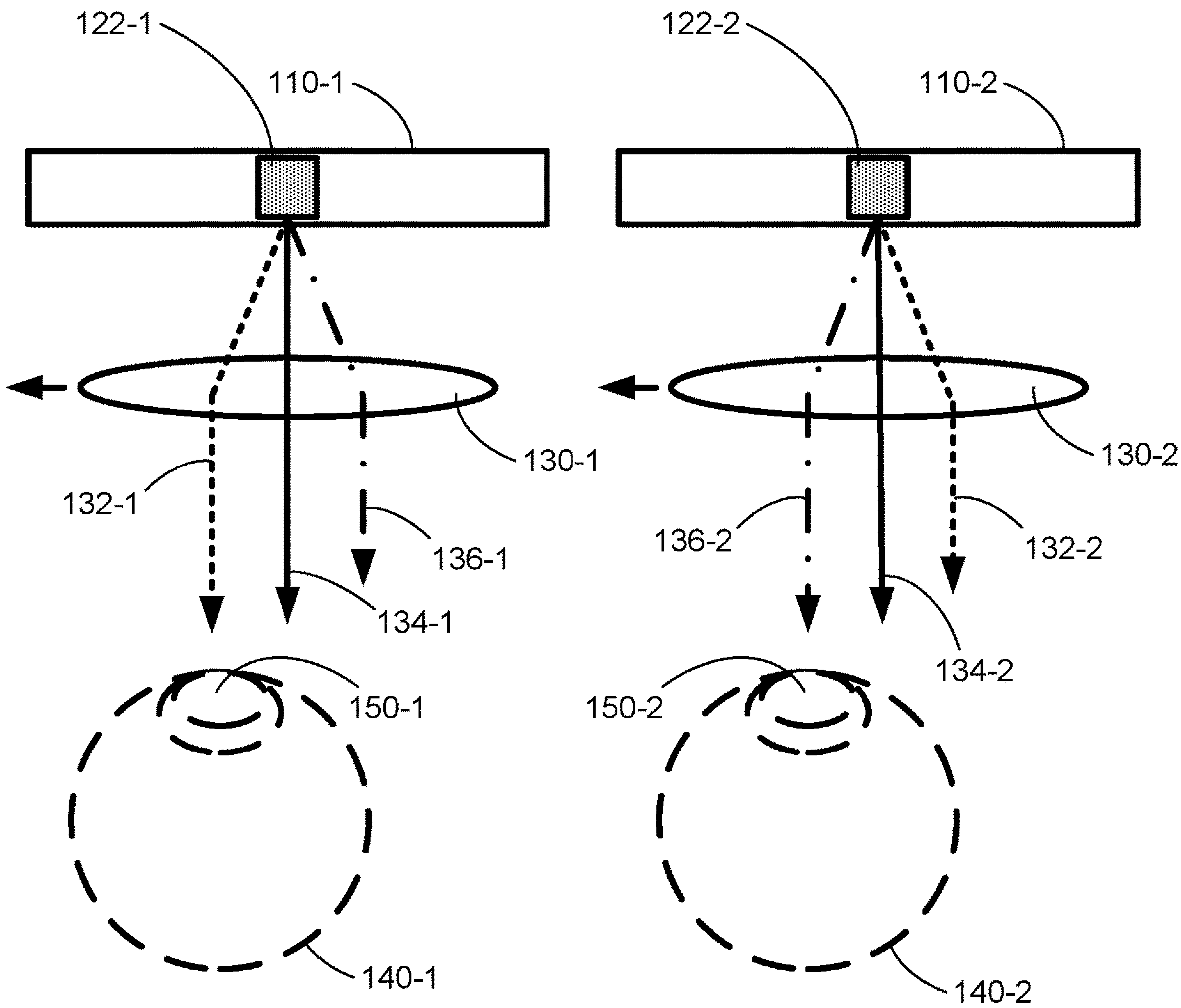
134-1
134-2
132-2
150-1
150-2
140-1
140-2

Figure 1D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110-1
122-2
110-2
130-1
130-2
132-1
136-1
134-1
136-2
132-2
134-2
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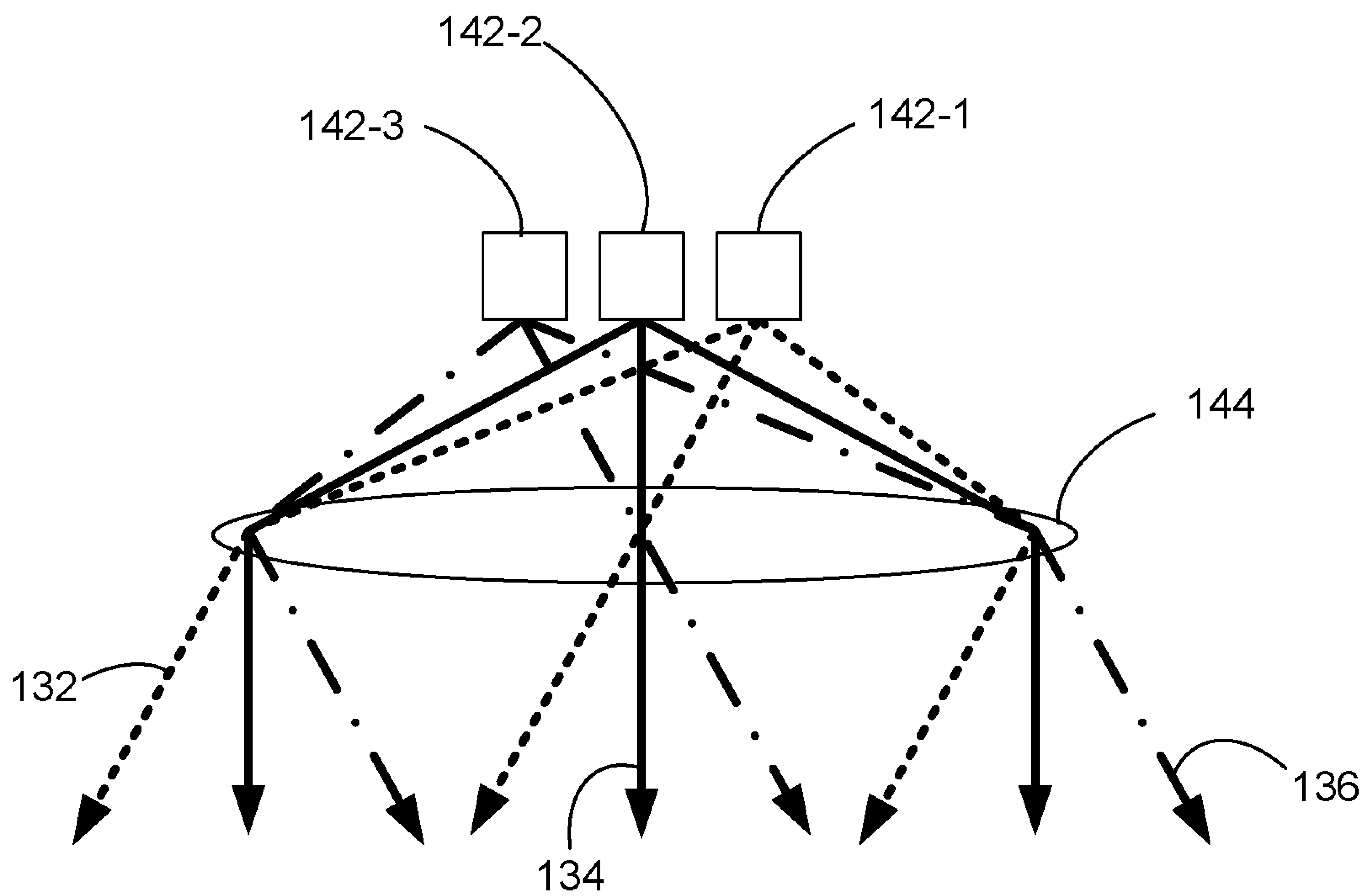
150-2
140-1
140-2

Figure 1E



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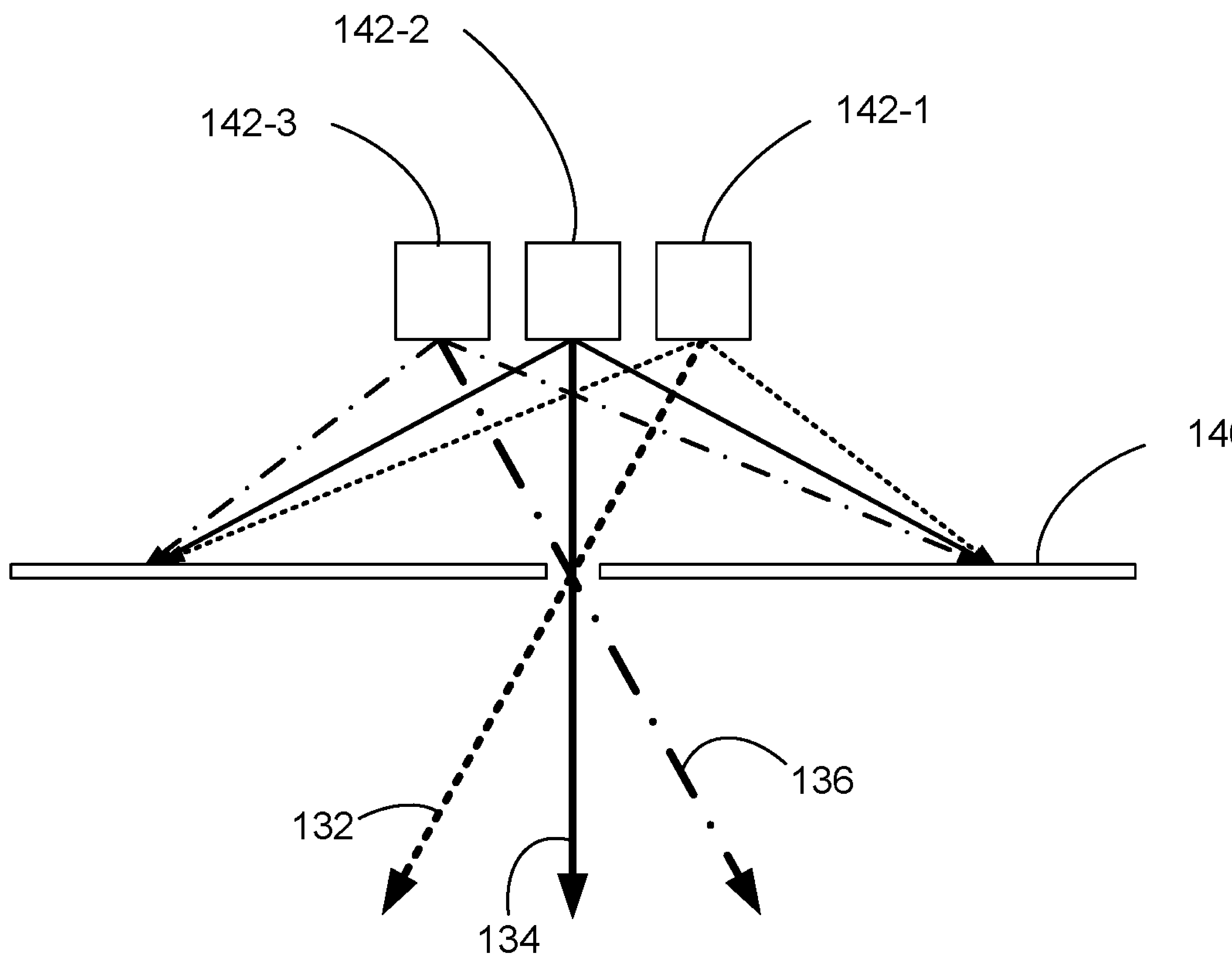


Figure 1G

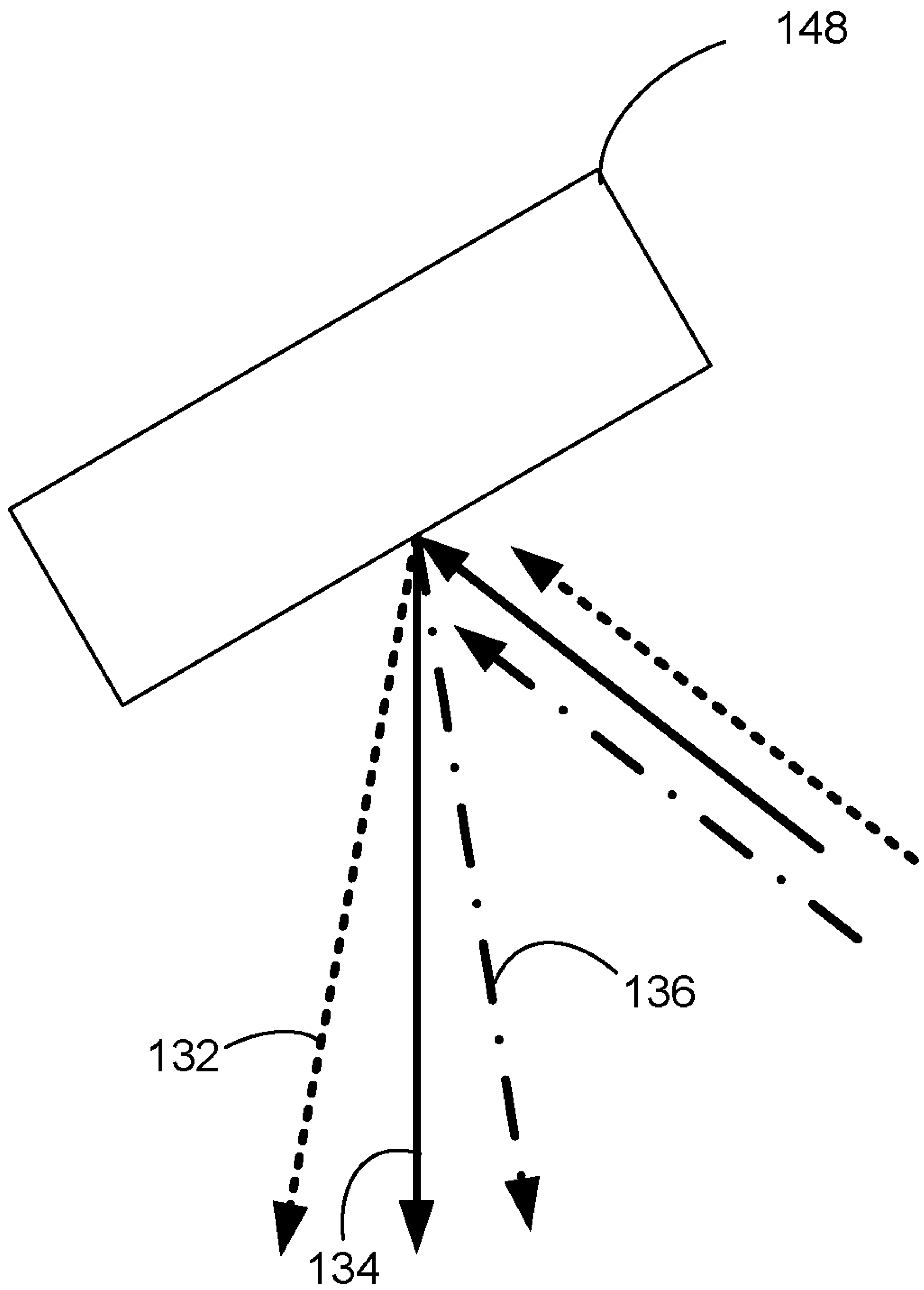


Figure 1H

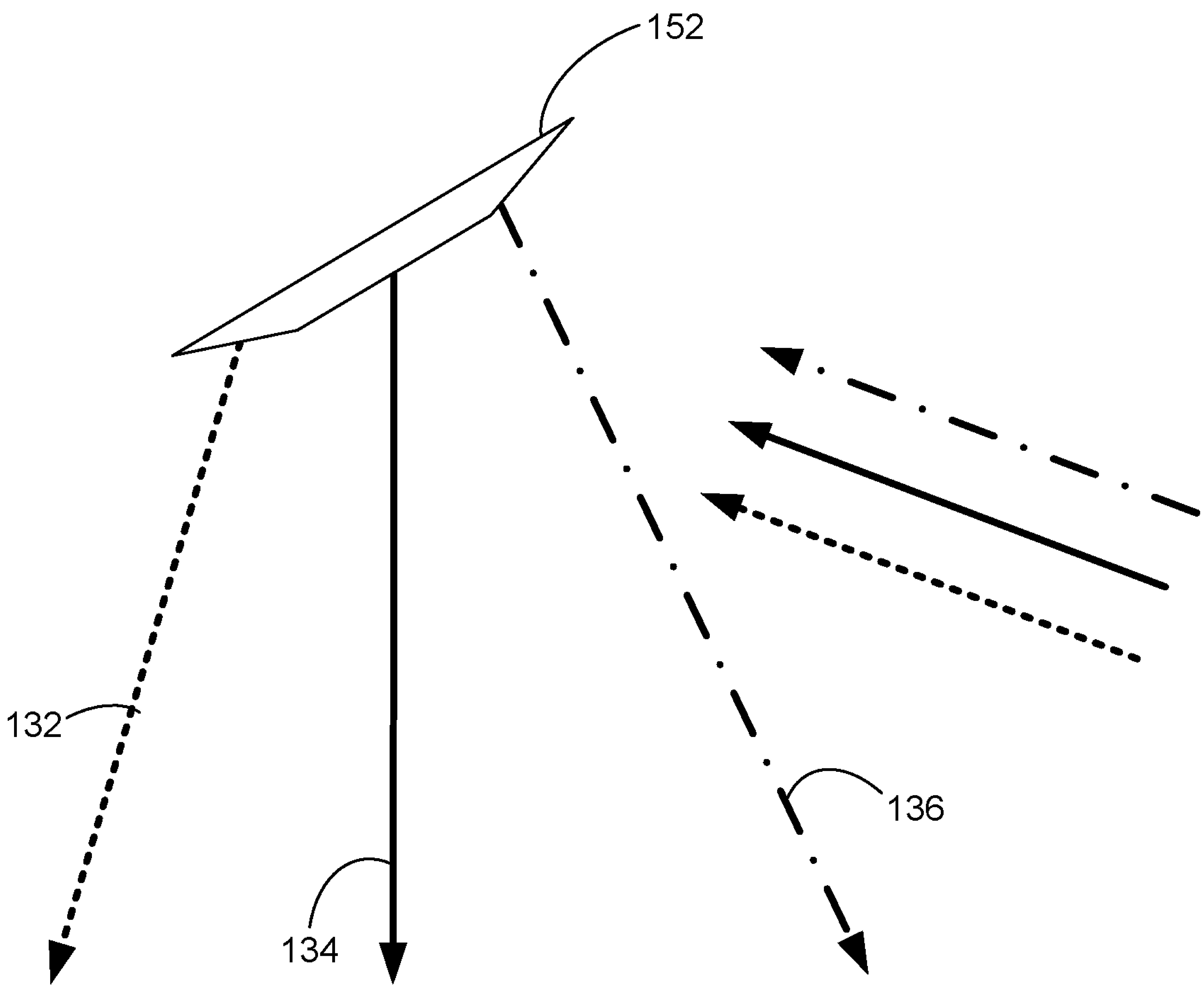


Figure 1I

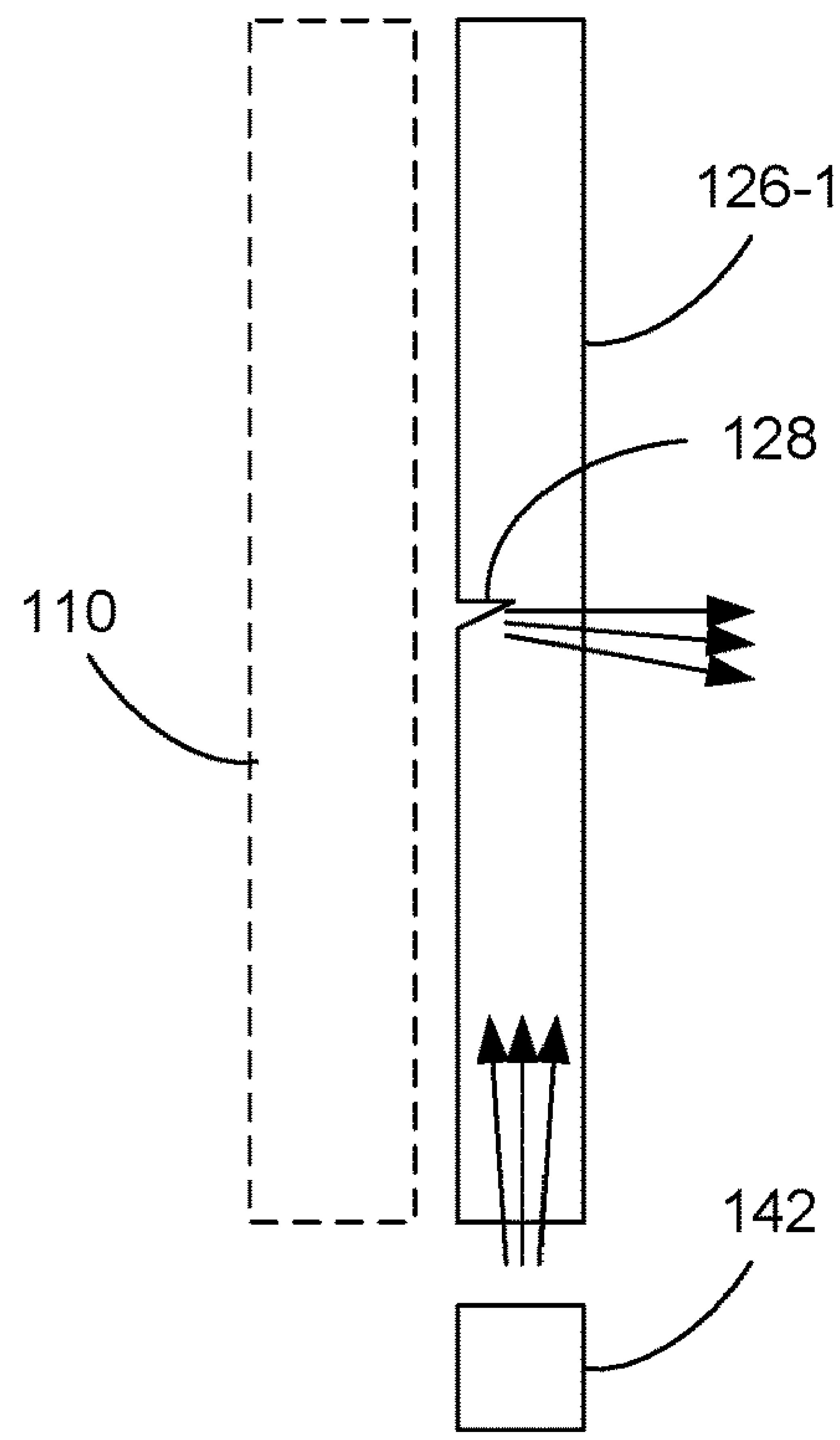
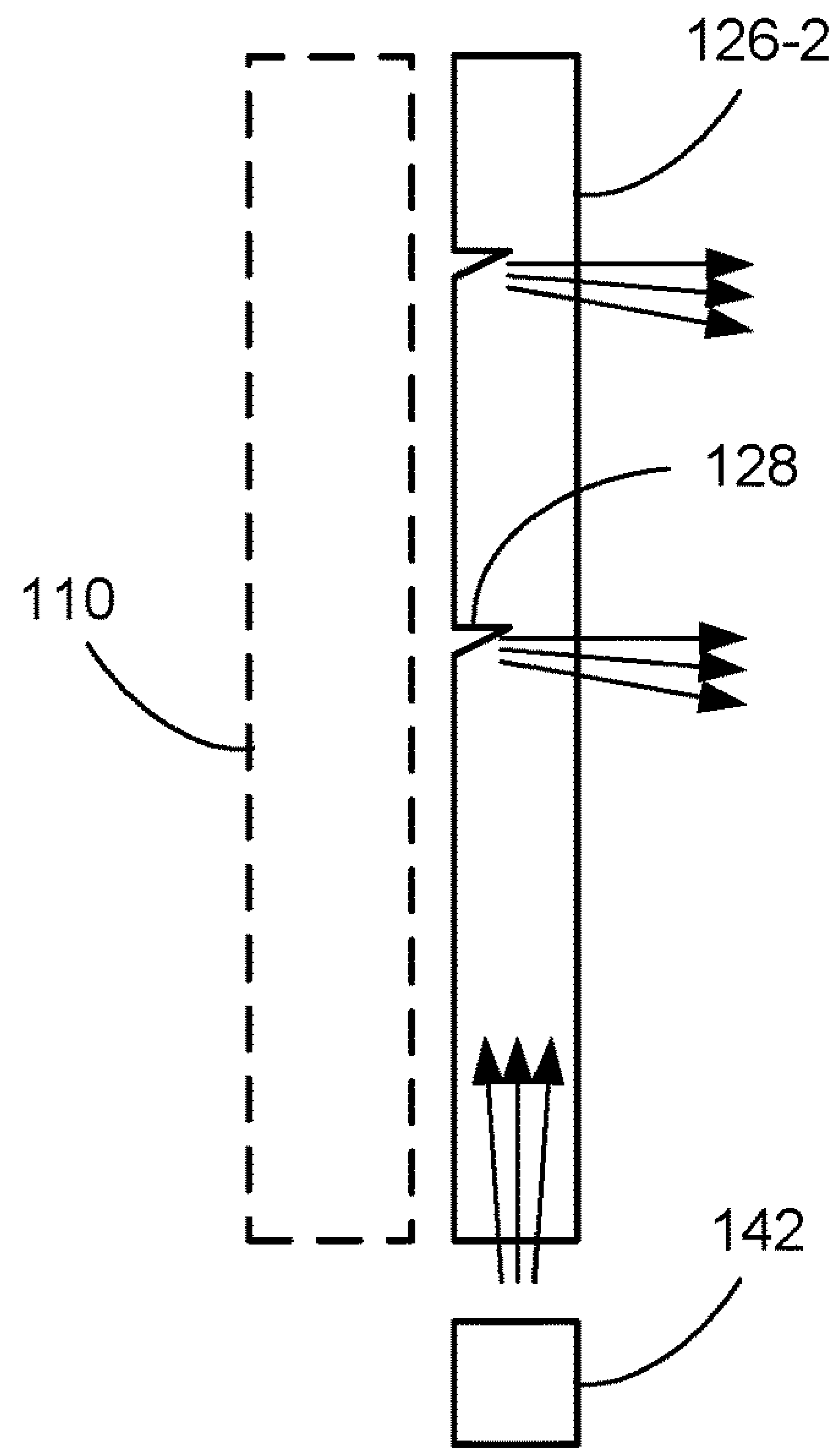


Figure 1J



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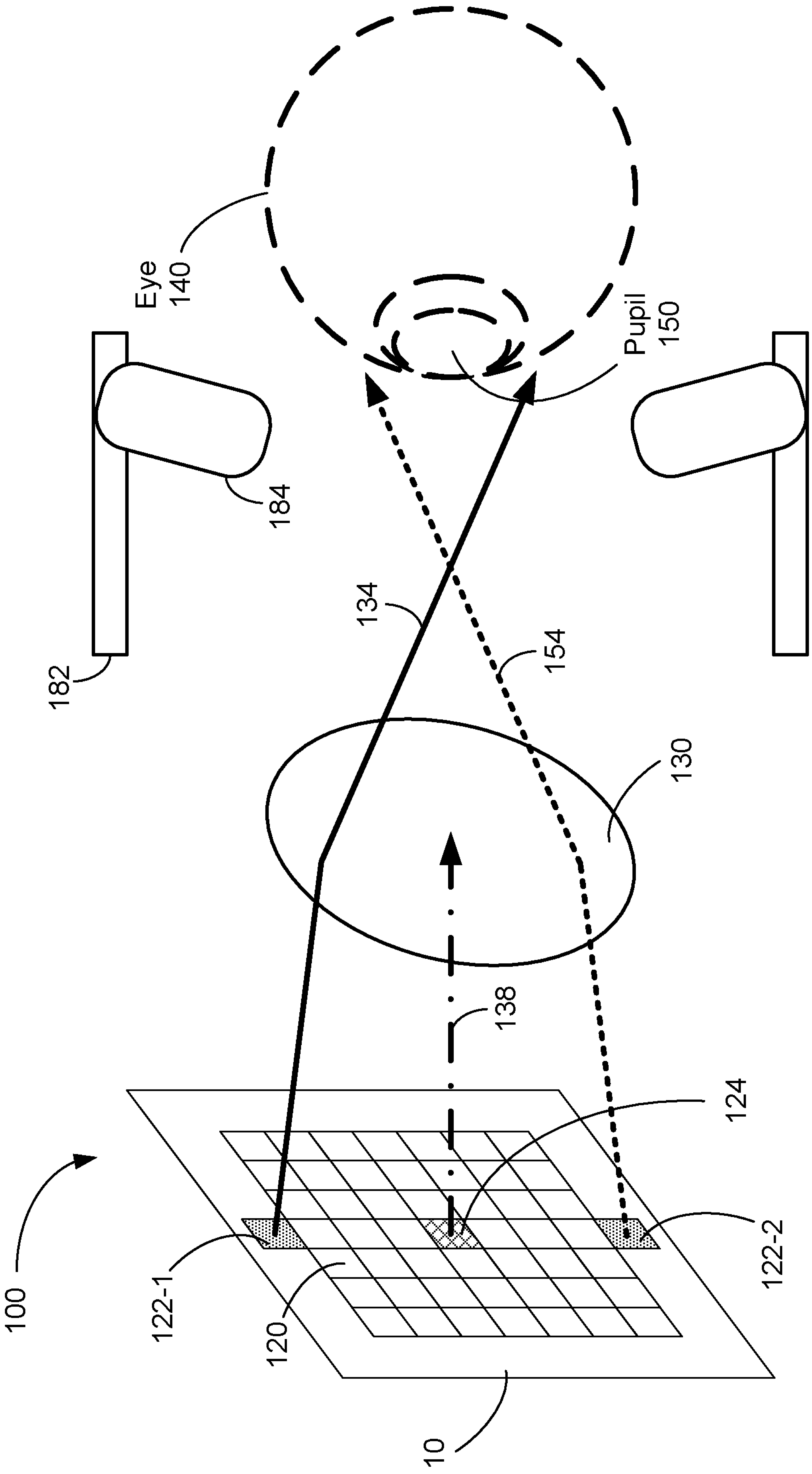
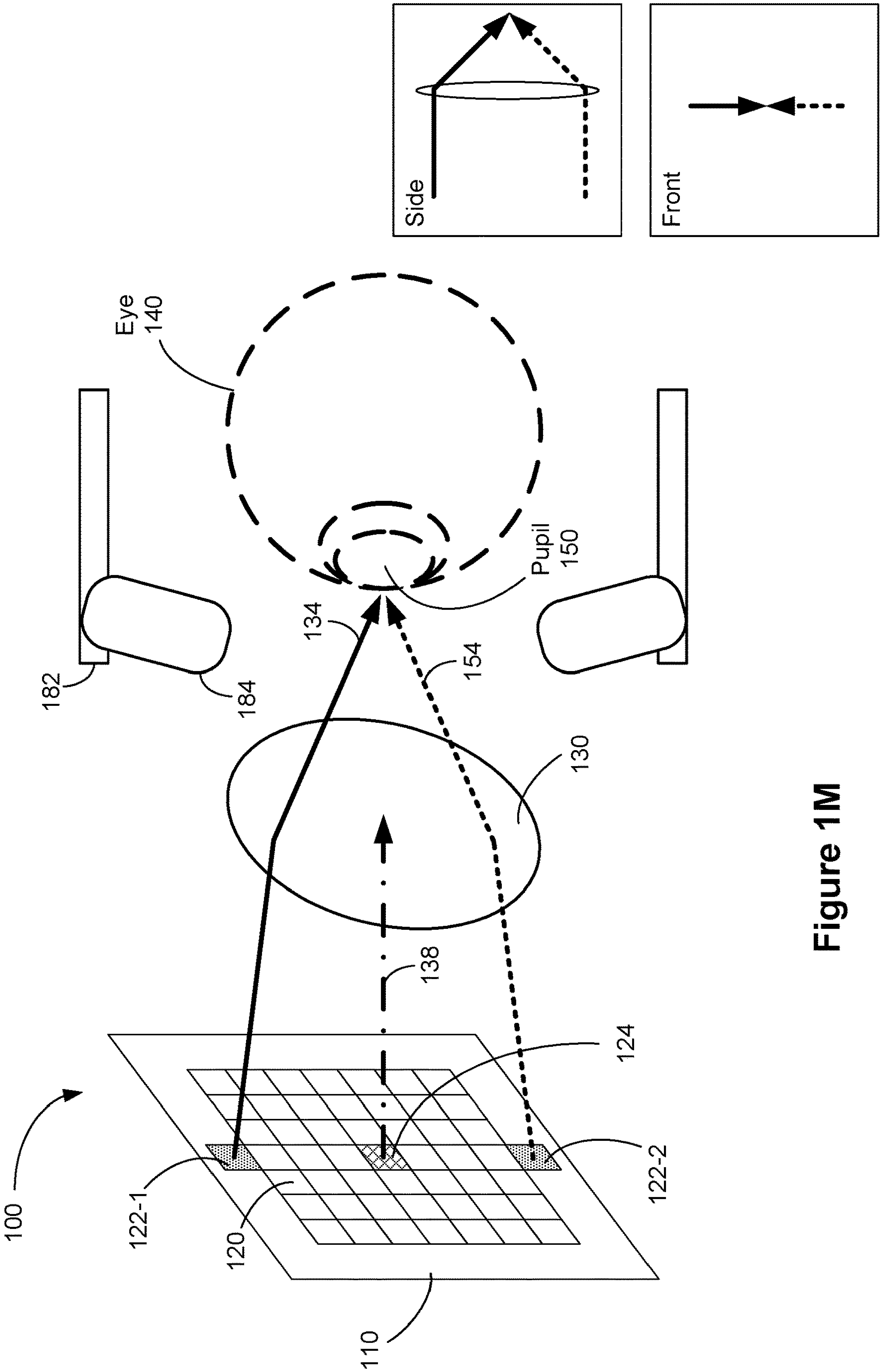

Eye
140
Pupil
150
184
182
134
154
130
138
124
100
122-1
120
122-2
110

Figure 1L



Side
Front
Eye
140
Pupil
150
134
154
182
184
130
138
124
100
122-1
120
122-2
110

Figure 1M

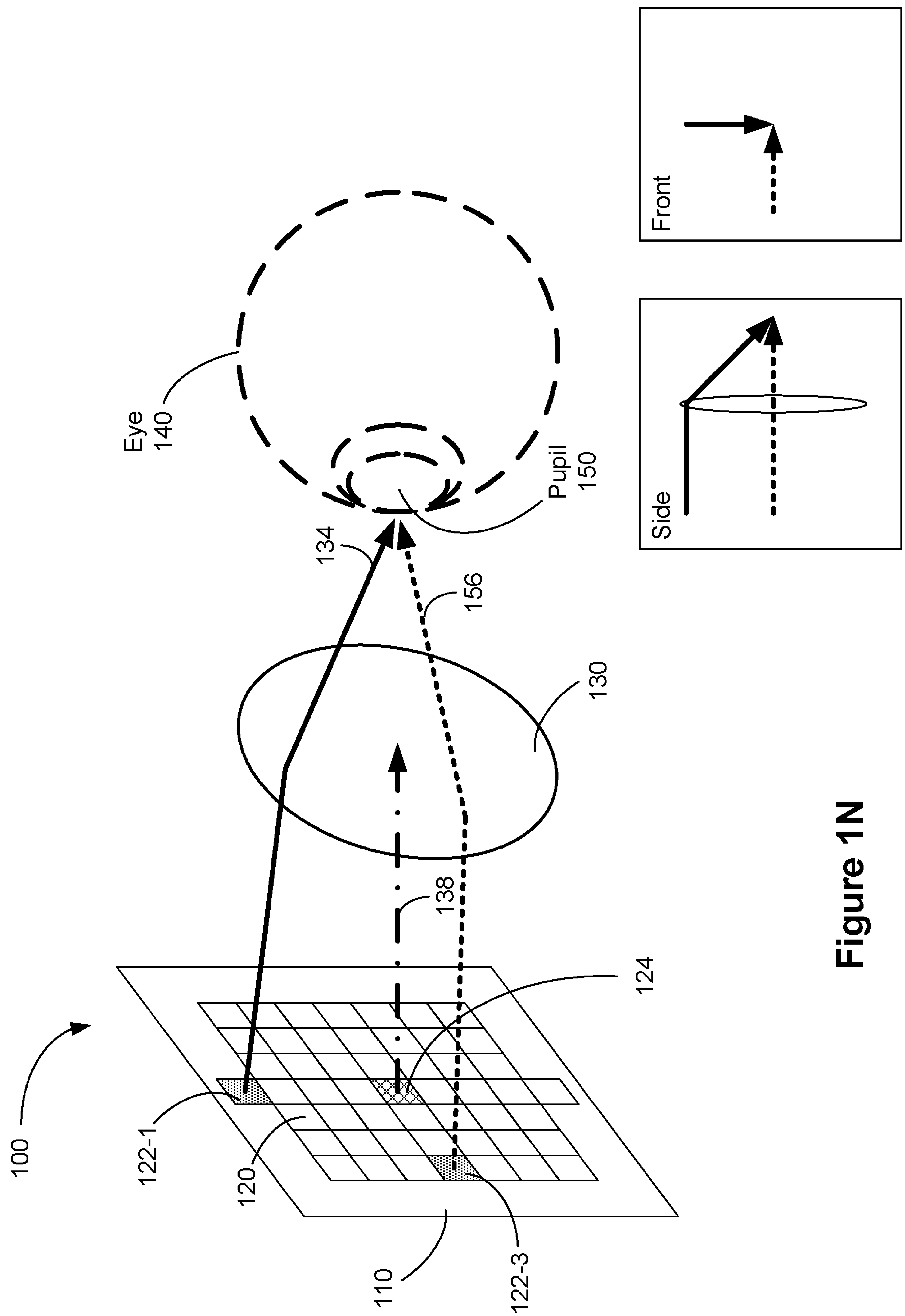

100
122-1
120
110
122-3
124
138
130
134
156
Eye
140
Pupil
150
Side
Front

Figure 1N

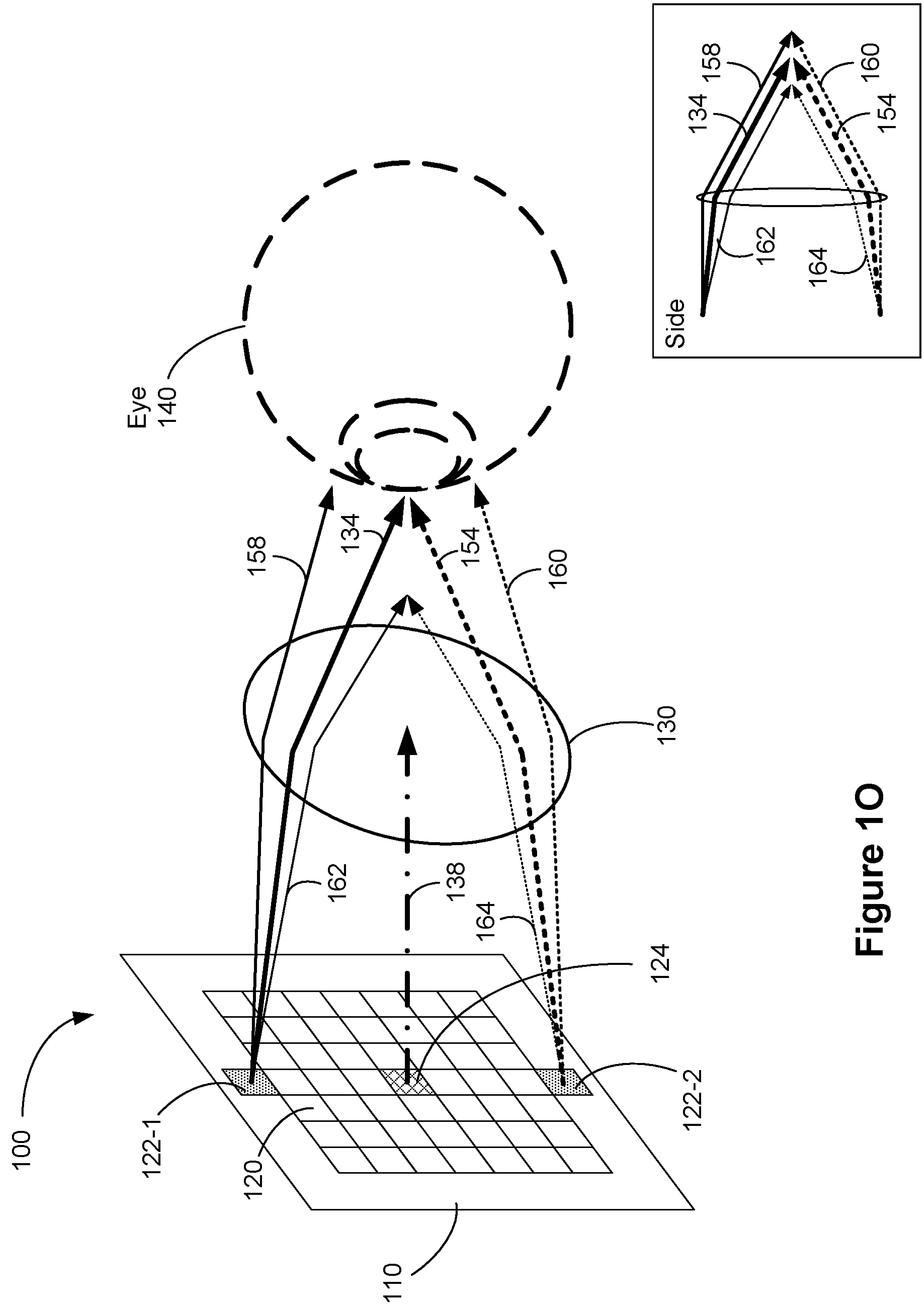

100
110
120
122-1
122-2
124
130
134
138
154
158
160
162
164
Eye
140
Side

Figure 1O

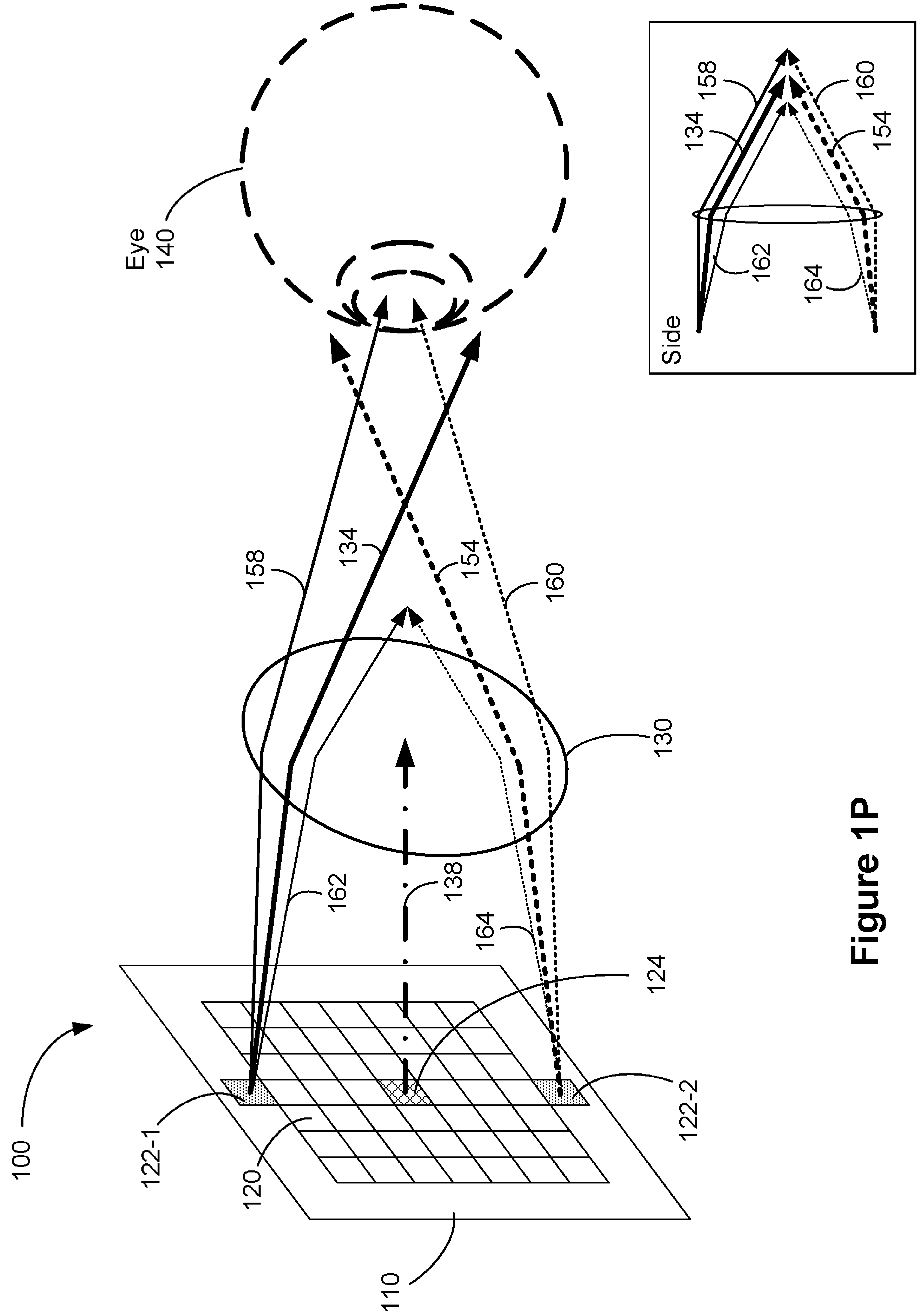

Eye
140
158
134
154
160
Side
162
164
130
138
124
100
122-1
120
122-2
110

Figure 1P

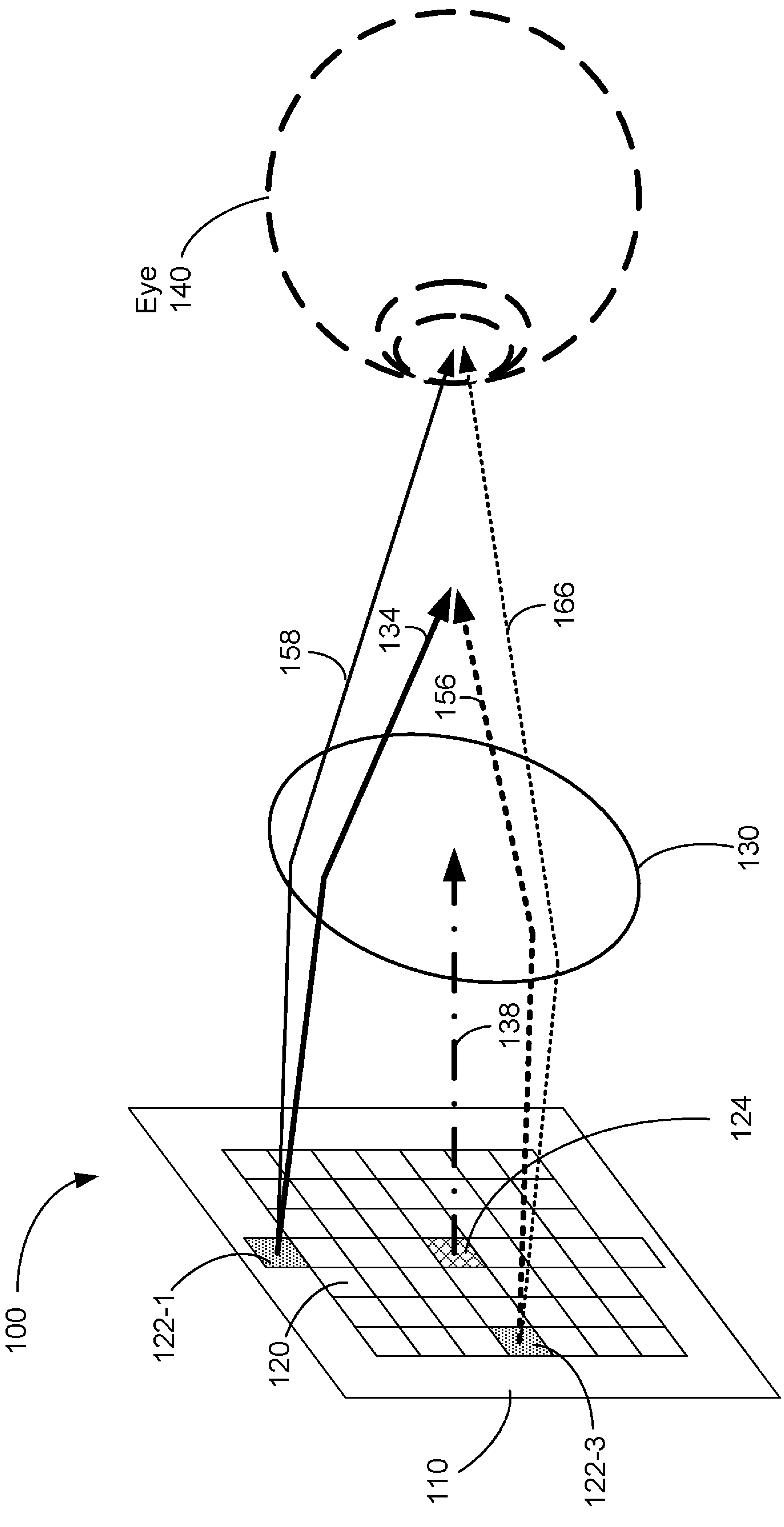


Figure 1Q

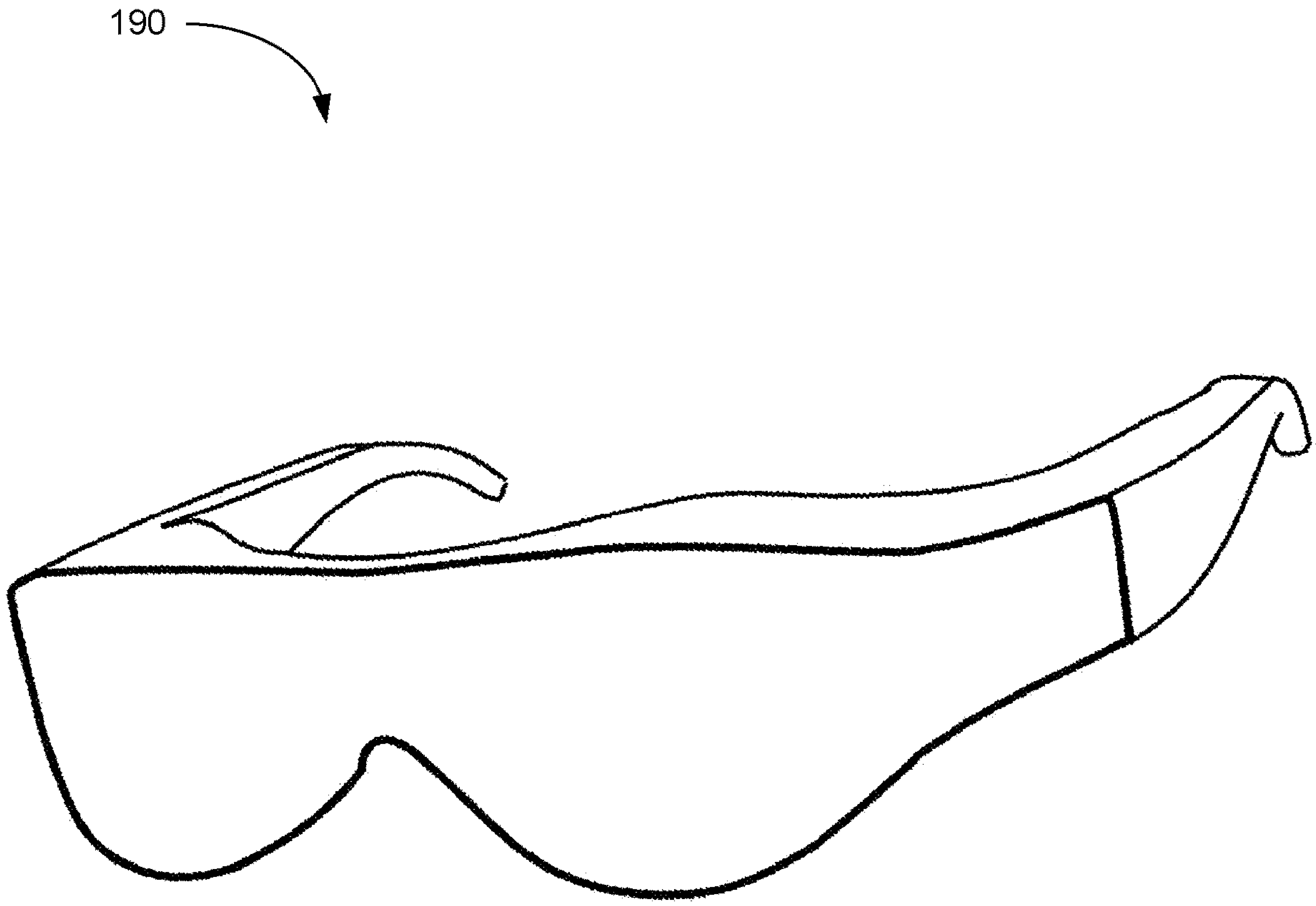


Figure 1R

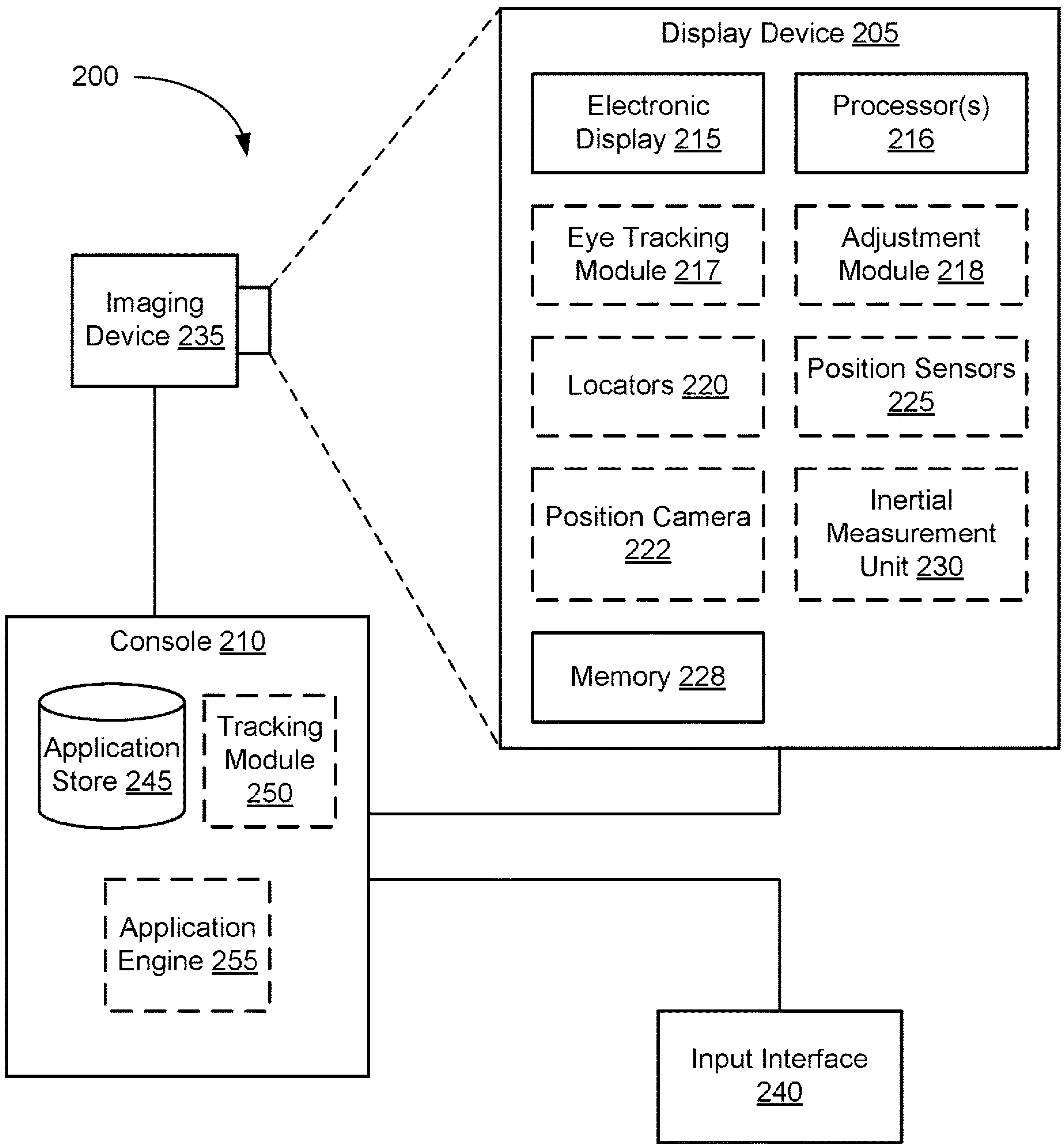

200
Display Device 205
Electronic Display 215
Processor(s) 216
Eye Tracking Module 217
Adjustment Module 218
Locators 220
Position Sensors 225
Position Camera 222
Inertial Measurement Unit 230
Memory 228
Imaging Device 235
Console 210
Application Store 245
Tracking Module 250
Application Engine 255
Input Interface 240

Figure 2

DEVICES AND METHODS FOR ADJUSTING LENS POSITIONS BASED ON ENCODED LIGHT PATTERNS

RELATED APPLICATION

This application is related to U.S. patent application Ser. No. 15/583,952, entitled "Devices and Methods for Adjusting an Interpupillary Distance Based on Encoded Light Patterns" filed May 1, 2017, which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

This relates generally to display devices, and more specifically to head-mounted display devices.

BACKGROUND

Head-mounted display devices (also called herein head-mounted displays) are gaining popularity as means for providing visual information to user. Different users can have different interpupillary distances, and it is important to set up a head-mounted display device for the correct interpupillary distance of a user, as an incorrect interpupillary distance can cause visual distortion.

However, determining an accurate interpupillary distance has often required professional assistance (e.g., a measurement by an optician). In the absence of such professional assistance, users often set up display devices for incorrect interpupillary distances, which reduces the user experience with such devices.

In addition, placing an eye of a user at an appropriate distance from an exit pupil (e.g., a last lens) of a head-mounted display device is also important. When the eye is located at a position that does not correspond to a design eye relief, the field of view is reduced, which also reduces the user experience with the head-mounted display device.

SUMMARY

Accordingly, there is a need for an improved method and an improved device for adjusting an interpupillary distance, thereby improving the user experience with display devices. In addition, there is a need for an improved method and an improved device for adjusting an eye relief, thereby improving the user experience with display devices.

The above deficiencies and other problems are reduced or eliminated by the disclosed devices and methods.

In accordance with some embodiments, a device includes a first light source device configured to transmit a first light in a first direction and a second light in a second direction that is distinct from the first direction; and a first set of one or more lenses configured for directing the first light and the second light from the first light source device toward a first eye of a user. The first light is spatially offset from the second light and one or more of the first light and the second light provide a cue for adjusting a location of the first set of one or more lenses.

In accordance with some embodiments, a method includes transmitting a first light in a first direction and a second light that is distinct from the first light in a second direction that is distinct from the first direction; and transmitting the first light and the second light through a first set of one or more lenses and directing the first light and the second light toward a first eye of a user. The first light is spatially offset from the second light and one or more of the first light and the second light provide a cue for adjusting a location of the first set of one or more lenses.

In accordance with some embodiments, a method includes receiving a portion of a bundle of light that includes a first light and a second light that is distinct from the first light and laterally offset from the first light; and, in accordance with a determination that the received portion of the bundle of light corresponds to the first light, moving the first set of one or more lenses.

In accordance with some embodiments, a device includes a first light source device configured to transmit a first light in a first direction; a second light source device configured to transmit a second light in a second direction; and a first set of one or more lenses configured for directing, toward a first eye of a user, the first light from the first light source device and the second light from the second light source device so that the first light intersects with the second light at a first location. One or more of the first light and the second light provide a cue for adjusting a location of the first set of one or more lenses relative to the first eye of the user.

In accordance with some embodiments, a method includes transmitting, from a first light source device, a first light in a first direction and transmitting, from a second light source device, a second light that is distinct from the first light in a second direction. The method also includes transmitting the first light and the second light through a first set of one or more lenses and directing the first light and the second light toward a first eye of a user.

In accordance with some embodiments, a method includes receiving a portion of a light beam that includes a first light from a first light source device and a second light that is distinct from the first light from a second light source device. The first light and the second light have been transmitted through a first set of one or more lenses. After transmitting through the first set of one or more lenses, the first light is configured to intersect with the second light. The method also includes, in accordance with a determination that the received portion of the light beam does not include both the first light and the second light, adjusting an eye relief.

Thus, the disclosed embodiments provide devices and methods that facilitate accurate determination and/or adjustment of interpupillary distances. In addition, the disclosed embodiments provide devices and methods that facilitate accurate determination and/or adjustment of eye reliefs.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the various described embodiments, reference should be made to the Description of Embodiments below, in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

FIG. **1**A is a schematic diagram of a device for determining and/or adjusting an offset of a lens in accordance with some embodiments.

FIG. **1**B is a schematic diagram illustrating an example configuration where lenses are aligned with eyes.

FIGS. **1**C-**1**E are schematic diagrams illustrating example configurations where lenses are not aligned with eyes.

FIGS. **1**F-**1**K are schematic diagrams illustrating example light source devices in accordance with some embodiments.

FIGS. **1**L-**1**M are schematic diagrams illustrating a device for providing optical cues for adjusting a distance between an optical element and an eye in accordance with some embodiments.

FIG. **1**N is a schematic diagram illustrating a device for providing optical cues for adjusting a distance between an optical element and an eye in accordance with some embodiments.

FIGS. **1**O-**1**P are schematic diagrams illustrating a device for providing optical cues for adjusting a distance between an optical element and an eye in accordance with some embodiments.

FIG. **1**Q is a schematic diagram illustrating a device for providing optical cues for adjusting a distance between an optical element and an eye in accordance with some embodiments.

FIG. **1**R is a perspective view of a device in accordance with some embodiments.

FIG. **2** is a block diagram of a system including a display device in accordance with some embodiments.

These figures are not drawn to scale unless indicated otherwise.

DETAILED DESCRIPTION

Many viewing optics (e.g., eyeglasses, head-mounted display devices, etc.) require a correct positioning of the viewing optics relative to a position of an eye. Incorrect positioning of viewing optics can cause visual distortion. However, determining an accurate interpupillary distance has often required professional assistance (e.g., a measurement by an optician). In the absence of such professional assistance, users can set up viewing optics for incorrect interpupillary distances. For example, users may be asked to adjust lateral positions of lenses until a crosshair appears the sharpest. Certain users may not be able to accurately determine when the crosshair appears the sharpest.

The disclosed device, including a light source device coupled with one or more lenses, allows accurate determination and/or adjustment of an interpupillary distance utilizing a projection of an encoded light pattern. In addition, the disclosed device allows accurate determination and/or adjustment of an eye relief utilizing a projection of an encoded light pattern.

In some embodiments, the light source device and the one or more lenses are included in a head-mounted display device, which is, in turn, used for providing virtual reality and/or augmented reality content. In some embodiments, the light source device and the one or more lenses are included in a stand-alone diagnostic device for determining an interpupillary distance.

Reference will now be made to embodiments, examples of which are illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide an understanding of the various described embodiments. However, it will be apparent to one of ordinary skill in the art that the various described embodiments may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

It will also be understood that, although the terms first, second, etc. are, in some instances, used herein to describe various elements, these elements should not be limited by these terms. These terms are used only to distinguish one element from another. For example, a first lens could be termed a second lens, and, similarly, a second lens could be termed a first lens, without departing from the scope of the various described embodiments. The first lens and the second lens are both lenses, but they are not the same lens.

The terminology used in the description of the various described embodiments herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the description of the various described embodiments and the appended claims, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "includes," "including," "comprises," and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The term "exemplary" is used herein in the sense of "serving as an example, instance, or illustration" and not in the sense of "representing the best of its kind."

FIG. **1**A is an isometric view of display device **100** in accordance with some embodiments. In some other embodiments, display device **100** is part of some other electronic display (e.g., head-mounted displays, digital microscope, etc.). In some embodiments, display device **100** includes light emission device array **110** and one or more lenses (e.g., lens **130**). Light emission device array **110** emits image light toward a viewing user.

In some embodiments, light emission device array **110** includes light emission devices **120** (e.g., pixels) that emit light in the visible light. For example, light emission device array **110** includes an array of light-emitting diodes (LEDs), an array of microLEDs, an array of OLEDs, or some combination thereof.

In some embodiments, light emission device array **110** includes one or more light sources (e.g., a fluorescent light source or a broadband light source, such as a white LED) and an emission intensity array. The emission intensity array is configured to selectively attenuate light emitted from the one or more light sources. In some embodiments, the emission intensity array is composed of a plurality of liquid crystal cells or pixels. Each of the liquid crystal cells is, or in some embodiments, groups of liquid crystal cells are, addressable to have specific levels of attenuation. For example, at a given time, some of the liquid crystal cells may be set to no attenuation, while other liquid crystal cells may be set to maximum attenuation. In this manner, the emission intensity array is able to control what portion of the image light emitted from the one or more light sources is passed to the one or more lenses (e.g., lens **130**). In some embodiments, the one or more light sources include light emission devices **120**, such as an array of LEDs, an array of microLEDs, an array of OLEDs, or a combination thereof.

One or more lenses (e.g., lens **130**) receive light from emission device array **110**, and direct the light to a location of pupil **150**. In some embodiments, lens **130** includes one or more diffractive optics. In some embodiments, the one or more lenses include active lens. An active lens is a lens whose lens curvature and/or refractive ability may be dynamically controlled (e.g., via a change in applied voltage). An active lens may be a liquid crystal lens, a liquid lens (e.g., using electro-wetting), or some other lens whose curvature and/or refractive ability may be dynamically controlled, or some combination thereof. Accordingly, in some embodiments, system **200** (described with respect to FIG. **2**) may dynamically adjust the curvature and/or refractive ability of active lenslets to direct light received from light emission device array **110** to pupil **150**.

FIG. **1**A also illustrates one or more light source devices **122** (e.g., light source device **122-1** and/or light source device **122-2**) are located adjacent to light emission device array **110**. In some embodiments, one or more light source devices **122** are integrated with light emission device array **110**. In some embodiments, one or more light source devices **122** are separate from light emission device array **110**, but one or more light source devices **122** are located in proximity to light emission device array **110** (e.g., one or more light source devices **122** are located on light emission device array **110**). In some embodiments, light source device **122** (e.g., light source device **122-1** and/or light source device **122-2**) is located adjacent to a top or bottom edge of light emission device array **110**.

In some embodiments, light source device **122** (e.g., light source device **122-1** and/or light source device **122-2**) is located adjacent to a center of atop or bottom edge of light emission device array **110**. For example, in FIG. **1**A, light source device **122-1** is located adjacent to a center of atop edge of light emission device array **110**, and light source device **122-2** is located adjacent to a center of a bottom edge of light emission device array **110**. In some embodiments, a light source device (e.g., light source device **122-1** or light source device **122-2**) is located within at least 1 mm, 2 mm, 3 mm, 4 mm, or 5 mm from a center of a top or bottom edge of light emission device array **110**. In some embodiments, the device provides to a user instructions to look toward light source device **122** (e.g., look up or look down, depending on the location of light source device **122**).

In FIG. **1**A, light source device **122-1** emits first light **132** (e.g., a red light) in a first direction, second light **134** (e.g., a green light) in a second direction, and third light **136** (e.g., a blue light) in a third direction. First light **132**, second light **134**, and third light **136** are spatially separated. In some cases, only one of first light **132**, second light **134**, and third light **136** enters through pupil **150** of eye **140** depending on a position of eye **140** (e.g., a position of pupil **150** of eye **140**). Thus, the projection of first light **132**, second light **134**, and third light **136** can be used to determine whether lens **130** is aligned with eye **140**.

In some embodiments, light emission device array **110** also displays additional features for assisting a user with determining whether lens **130** is aligned with eye **140**. In FIG. **1**A, one or more light emission devices **120** (e.g., such as pixel **124**) of light emission device array **110** optionally emit reference light **138**. In some embodiments, reference light **138** corresponds to second light **134** (e.g., reference light **138** has a same color and/or a same pulsing frequency as second light **134**) so that reference light **138** can serve as a guide for determining whether lens **130** is aligned with eye **140**. In some embodiments, light emission device array **110** optionally displays instructions for guiding users in adjusting the position of lens **130**.

FIG. **1**B is a schematic diagram illustrating an example configuration (e.g., an example plan view) where lenses are aligned with eyes.

In FIG. **1**B, the device includes light source device **122-1** and light source device **122-2**. In some embodiments, light source device **122-1** is coupled with light emission device array **110-1** (e.g., a display screen) and light source device **122-2** is coupled with light emission device array **110-2** (e.g., a display screen). In some embodiments, light source device **122-1** is located adjacent to a lateral center of light emission device array **110**. In some embodiments, light source device **122-1** is located adjacent to a lateral center of a top or bottom edge of light emission device array **110**.

Light source device **122-1** emits first light **132-1** (e.g., a red light) in a first direction, second light **134-1** (e.g., a green light) in a second direction, and third light **136-1** (e.g., a blue light) in a third direction. First light **132-1**, second light **134-1**, and third light **136-1** from light source device **122-1** are transmitted through lens **130-1**, which direct first light **132-1**, second light **134-1**, and third light **136-1** toward eye **140-1** (e.g., a left eye). For example, first light **132-1**, second light **134-1**, and third light **136-1** are collimated after passing through lens **130-1**. In some embodiments, light source device **122-1** is located at a focal plane of lens **130-1**. As shown in FIG. **1**B, first light **132-1** is spatially separated from second light **134-1** and third light **136-1**, and second light **134-1** is spatially separated from third light **136-1**, after passing through lens **130-1**. In some embodiments, first light **132-1** is parallel to second light **134-1** and third light **136-1** after passing through lens **130-1**. In some embodiments, first light **132-1** is spatially offset from second light **134-1** by at least 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm. In some embodiments, second light **134-1** is spatially offset from third light **136-1** by at least 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm.

Similarly, light source device **122-2** emits fourth light **132-2** (e.g., a red light) in a fourth direction, fifth light **134-2** (e.g., a green light) in a fifth direction, and sixth light **136-2** (e.g., a blue light) in a sixth direction. Fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** from light source device **122-2** are transmitted through lens **130-2**, which direct fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** toward eye **140-2** (e.g., a right eye). For example, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** are collimated after passing through lens **130-2**. In some embodiments, light source device **122-2** is located at a focal plane of lens **130-2**. As shown in FIG. **1**B, fourth light **132-2** is spatially separated from fifth light **134-2** and sixth light **136-2**, and fifth light **134-2** is spatially separated from sixth light **136-2**, after passing through lens **130-2**. In some embodiments, fourth light **132-2** is parallel to fifth light **134-2** and sixth light **136-2** after passing through lens **130-2**. In some embodiments, fourth light **132-2** is spatially offset from fifth light **134-2** by at least 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm. In some embodiments, fifth light **134-2** is spatially offset from sixth light **136-2** by at least 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm.

In FIG. **1**B, a lateral position of eye **140-1** is aligned with a lateral position of lens **130-1** (e.g., a lateral position of an optical center of lens **130-1**), and second light **134-1** (e.g., a green light) enters through pupil **150-1** of eye **140-1**. In addition, a lateral position of eye **140-2** is aligned with a lateral position of lens **130-2** (e.g., a lateral position of an optical center of lens **130-2**), and fifth light **134-2** (e.g., a green light) enters through pupil **150-2** of eye **140-2**. FIG. **1**B also shows that first light **132-1** (e.g., a red light) and third light **136-1** (e.g., a blue light) do not enter through pupil **150-1** of eye **140-1**, and fourth light **132-2** (e.g., a red light) and sixth light **136-2** (e.g., a blue light) do not enter through pupil **150-2** of eye **140-2**. Second light **134-1** (e.g., a green light) received with eye **140-1** indicates that a lateral position of lens **130-1** is aligned with a lateral position of eye **140-1** and fifth light **134-2** (e.g., a green light) received with eye **140-2** indicates that a lateral position of lens **130-2** is aligned with a lateral position of eye **140-2**. Thus, no adjustment of the lateral position of lens **130-1** or the lateral position of lens **130-2** is necessary.

FIGS. **1**C-**1**E are schematic diagrams illustrating example configurations where lenses are not aligned with eyes.

In FIG. **1**C, third light **136-1** (e.g., a blue light) enters through pupil **150-1** of eye **140-1**. In addition, sixth light **136-2** (e.g., a blue light) enters through pupil **150-2** of eye **140-2**. FIG. **1**C also shows that first light **132-1** (e.g., a red light) and second light **134-1** (e.g., a green light) do not enter through pupil **150-1** of eye **140-1**, and fourth light **132-2** (e.g., a red light) and fifth light **134-2** (e.g., a green light) do not enter through pupil **150-2** of eye **140-2**. Third light **136-1** (e.g., a blue light) received with eye **140-1** indicates that a lateral position of lens **130-1** is located on the left side of a lateral position of eye **140-1**, and sixth light **136-2** (e.g., a blue light) received with eye **140-2** indicates that a lateral position of lens **130-2** is located on the right side of a lateral position of eye **140-2**.

When lens **130-1** and lens **130-2** are included in a head-mounted display device, this indicates that the head-mounted display device is configured for an interpupillary distance shorter than the interpupillary distance of the user. Thus, the user can adjust the distance between lens **130-1** and lens **130-2** (e.g., increasing an interpupillary distance setting for the head-mounted display device) until second light **134-1** (e.g., a green light) is received with eye **140-1** and fifth light **134-2** (e.g., a green light) is received with eye **140-2**, as shown in FIG. **1**B.

In FIG. **1**D, first light **132-1** (e.g., a red light) enters through pupil **150-1** of eye **140-1**. In addition, fourth light **132-2** (e.g., a red light) enters through pupil **150-2** of eye **140-2**. FIG. **1**D also shows that second light **134-1** (e.g., a green light) and third light **136-1** (e.g., a blue light) do not enter through pupil **150-1** of eye **140-1**, and fifth light **134-2** (e.g., a green light) and sixth light **136-2** (e.g., a blue light) do not enter through pupil **150-2** of eye **140-2**. First light **132-1** (e.g., a red light) received with eye **140-1** indicates that a lateral position of lens **130-1** is located on the right side of a lateral position of eye **140-1**, and fourth light **132-2** (e.g., a red light) received with eye **140-2** indicates that a lateral position of lens **130-2** is located on the left side of a lateral position of eye **140-2**.

When lens **130-1** and lens **130-2** are included in a head-mounted display device, this indicates that the head-mounted display device is configured for an interpupillary distance longer than the interpupillary distance of the user. Thus, the user can adjust the distance between lens **130-1** and lens **130-2** (e.g., decreasing an interpupillary distance setting for the head-mounted display device) until second light **134-1** (e.g., a green light) is received with eye **140-1** and fifth light **134-2** (e.g., a green light) is received with eye **140-2**, as shown in FIG. **1**B.

In FIG. **1**E, first light **132-1** (e.g., a red light) enters through pupil **150-1** of eye **140-1**. In addition, sixth light **132-2** (e.g., a blue light) enters through pupil **150-2** of eye **140-2**. FIG. **1**E also shows that second light **134-1** (e.g., a green light) and third light **136-1** (e.g., a blue light) do not enter through pupil **150-1** of eye **140-1**, and fourth light **132-2** (e.g., a red light) and fifth light **134-2** (e.g., a green light) do not enter through pupil **150-2** of eye **140-2**. First light **132-1** (e.g., a red light) received with eye **140-1** indicates that a lateral position of lens **130-1** is located on the right side of a lateral position of eye **140-1**, and sixth light **132-2** (e.g., a blue light) received with eye **140-2** indicates that a lateral position of lens **130-2** is located on the right side of a lateral position of eye **140-2**.

When lens **130-1** and lens **130-2** are included in a head-mounted display device, this indicates that the head-mounted display device is positioned off toward a right side of the user. Thus, the user can reposition the head-mounted display device on the user's head (e.g., push the head-mounted display device toward a left side of the user's head) until second light **134-1** (e.g., a green light) is received with eye **140-1** and fifth light **134-2** (e.g., a green light) is received with eye **140-2**, as shown in FIG. **1**B.

Although FIGS. **1**B-**1**E illustrate that the fourth direction corresponds to the third direction and the sixth direction corresponds to the first direction (e.g., for each lens, the red light is projected toward an outside of the head-mounted display and the blue light is projected toward an inside of the head-mounted display), in some embodiments, the fourth direction corresponds to the first direction and the sixth direction corresponds to the third direction (e.g., for each lens, the red light is projected toward a left side of the head-mounted display and the blue light is projected toward a right side of the head-mounted display).

Although FIGS. **1**B-IE described that first light **132-1**, second light **134-1**, third light **136-1**, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** have certain colors, additionally or alternatively, first light **132-1**, second light **134-1**, third light **136-1**, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** have a respective time-dependent intensity pattern (e.g., a pulsing frequency, a duty cycle, and/or an interval). For example, first light **132-1** has a first pulsing frequency (e.g., first light **132-1** pulses at the first pulsing frequency), second light **134-1** has a second pulsing frequency (e.g., second light **134-1** pulses at the second pulsing frequency), third light **136-1** has a third pulsing frequency (e.g., third light **136-1** pulses at the third pulsing frequency), fourth light **132-2** has a fourth pulsing frequency (e.g., fourth light **132-2** pulses at the fourth pulsing frequency), fifth light **134-2** has a fifth pulsing frequency (e.g., fifth light **134-2** pulses at the fifth pulsing frequency), and sixth light **136-2** has a sixth pulsing frequency (e.g., sixth light **136-2** pulses at the sixth pulsing frequency). The pulsing frequencies of first light **132-1**, second light **134-1**, third light **136-1**, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** can be used to determine whether lens **130-1** is aligned with eye **140-1** and lens **130-2** is aligned with eye **140-2**. In some embodiments, one or more of first light **132-1**, second light **134-1**, third light **136-1**, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2** have a respective time-independent intensity pattern.

In some embodiments, the device illustrated in FIGS. **1**B-**1**E is used to determine an interpupillary distance (e.g., the interpupillary distance is determined from the positions of lenses **130-1** and **130-2** when both lenses **130-1** and **130-2** are aligned with eyes **140-1** and **140-2**). Thus, in some embodiments, the device can be used as a device for measuring an interpupillary distance. In some embodiments, the device is included in, and/or coupled with, another optical device (e.g., a head-mounted display device as shown in FIG. **1**R, an optical microscope, binoculars, etc.) to adjust the optical device to match the interpupillary distance.

In addition, although FIGS. **1**B-IE illustrate adjusting positions of two lenses (e.g., adjusting an interpupillary distance, which frequently involves moving both lenses), it is possible to use an analogous method for adjusting a position of a single lens of a single lens system (e.g., a display system configured to operate with a single eye only), or separately adjusting a position of an individual lens of a multi-lens system.

Although FIGS. **1**B-IE illustrate the use of six light components (e.g., first light **132-1**, second light **134-1**, third light **136-1**, fourth light **132-2**, fifth light **134-2**, and sixth light **136-2**), in some embodiments, fewer or more light components can be used. For example, in some embodiments, both the first light and the third light have a same color (e.g., red) and the third light has a distinct color (e.g., green). In such embodiments, a light source device does not need to emit a light of a third color (e.g., a blue light). Thus, in some cases, a light of a first color (e.g., a green light) received with eye **140-1** indicates that a lateral position of lens **130-1** is aligned with a lateral position of eye **140-1**, and a light of a second color (e.g., a red light) received with eye **140-1** indicates that a lateral position of lens **130-1** is not aligned with a lateral position of eye **140-1** without indicating a direction of the misalignment (or in which direction lens **130-1** should move to match the lateral position of eye **140-1**). In some embodiments, light source device **122-1** emits light of four or more colors. This provides an additional resolution in adjusting the lateral position of lens **130-1**. In some embodiments, light source device **122-1** emits light having a continuous spectrum of colors as described below with FIGS. **1**H-**1**I.

FIGS. **1**F-**1**K are schematic diagrams illustrating example light source devices in accordance with some embodiments.

FIG. **1**F shows a light source device that includes first light emitting component **142-1**, second light emitting component **142-2**, and third light emitting component **142-3**. In some embodiments, each light emitting component is an LED, an organic LED (OLED), an array of LED and/or OLED, or a combination thereof.

In some embodiments, the light source device includes more or fewer light emitting components. First light emitting component **142-1** is configured to emit a first light, second light emitting component **142-2** is configured to emit a second light, and third light emitting component **142-3** is configured to emit a third light. In some embodiments, the first light has a first color (e.g., red) and/or a first time-dependent intensity pattern (e.g., a first pulsing frequency, a first duty cycle, and/or a first interval), the second light has a second color (e.g., green) and/or a second time-dependent intensity pattern (e.g., a second pulsing frequency, a second duty cycle, and/or a second interval), and the third light has a third color (e.g., blue) and/or a third time-dependent intensity pattern (e.g., a third pulsing frequency, a third duty cycle, and/or a third interval).

In some embodiments, first light emitting component **142-1**, second light emitting component **142-2**, and third light emitting component **142-3** are positioned on a focal plane of lens **144**, as shown in FIG. **1**F. In addition, first light emitting component **142-1**, second light emitting component **142-2**, and third light emitting component **142-3** are laterally offset from one another.

In some embodiments, lens **144** is rotationally symmetric (e.g., lens **144** is a spherical lens). In some embodiments, lens **144** is reflectionally symmetric (e.g., lens **144** is a cylindrical lens). In some embodiments, lens **144** is a two-dimensional lens (e.g., lens **144** is a spherical lens). In some embodiments, lens **144** is a one-dimensional lens (e.g., lens **144** is a cylindrical lens).

FIG. **1**F also shows that first light emitting component **142-1** emits light in multiple directions, and the light from first light emitting component **142-1** is directed to a first direction after passing through lens **144**. Second light emitting component **142-2** emits light in multiple directions, and the light from second light emitting component **142-2** is directed to a second direction after passing through lens **144**. Third light emitting component **142-3** emits light in multiple directions, and the light from third light emitting component **142-3** is directed to a third direction after passing through lens **144**. Thus, the light emitting device shown in FIG. **1**F is configured to transmit first light **132** in a first direction, second light **134** in a second direction, and third light **136** in a third direction.

FIG. **1**G shows a light source device that includes first light emitting component **142-1**, second light emitting component **142-2**, and third light emitting component **142-3**. First light emitting component **142-1**, second light emitting component **142-2**, and third light emitting component **142-3** are described above with respect to FIG. **1**F.

The light source device includes barrier **146** with an opening. In some embodiments, the opening is a pinhole. In some embodiments, the opening is a slit. The opening of barrier **146** transmits light having a particular direction from each light emitting component. For example, light from light emitting component **142-1** that is not directed to the opening is blocked by barrier **146**. Thus, the light emitting device shown in FIG. **1**G is configured to transmit first light **132** in a first direction, second light **134** in a second direction, and third light **136** in a third direction.

FIG. **1**H shows a light source device that includes optical grating **148**. In FIG. **1**H, optical grating **148** receives a light that includes multiple color components (e.g., the light includes two or more of a red light component, a green light component or a blue light component). In some embodiments, the light source device receives a white light. Optical grating **148** disperses the light components based on their respective wavelengths. For example, as shown in FIG. **1**H, optical grating **148** disperses first light **132** into a first direction, second light **134** into a second direction, and third light **136** into a third direction. In some embodiments, the light source device also includes a light source configured to provides the light with multiple color components (e.g., a broadband light source, such as an incandescent bulb, and a superluminescent light emitting diode, or a combination of multiple colored light emitting components shown in FIG. **1**F).

FIG. **1**I is similar to FIG. **1**H, except that set **152** of dichroic mirrors is used. In some embodiments, set **152** of dichroic mirrors include a single multi-faceted component, where each dichroic mirror is located on a respective facet. Each dichroic mirror is configured to reflect a light having a particular wavelength (or a range of wavelengths). Thus, the light emitting device shown in FIG. **1**G is configured to direct first light **132** in a first direction, second light **134** in a second direction, and third light **136** in a third direction.

FIG. **1**J shows a light source device that includes light guide **126-1** (e.g., an optical fiber) coupled with light emitting component **142** (e.g., a light emitting diode). Light from light emitting component **142** travels through light guide **126-1**. As shown in FIG. **1**J, light guide **126-1** has extraction feature **128**. In some embodiments, extraction feature **128** is an indentation prism. A portion of light traveling through light guide **126-1** is leaked, or emitted, from light guide **126-1** through extraction feature **128**. Based on the shape of extraction feature **128**, the emitted light is directed to a particular direction (e.g., by adjusting the angle of the indentation prism, the emitted light can be directed to a particular direction). In some embodiments, light guide **126-1** is made of a material that is transparent to visible light. Thus, when light guide **126-1** is placed over light emission device array **110**, the presence of light guide **126-1** is typically not perceived by a user (e.g., light guide **126-1** is not visible to the user). In addition, extraction feature **128** is configured so that extraction feature **128** does not visibly interfere with light emitted by light emission device array **110**. For example, extraction feature **128** is sized and/or positioned in a way such that extraction feature **128** does not interfere with light emitted by light emission device array **110** (e.g., extraction feature **128** is positioned over a dark region between pixels). The light source device shown in FIG. **1**J can be placed over light emission device array **110** without requiring a precise alignment between the light source device and light emission device array **110**. Thus, this can facilitate manufacturing of an optical device (e.g., a head-mounted display device).

FIG. **1**K is similar to FIG. **1**J, except that FIG. **1**K shows that light guide **126-2** can have multiple extraction features **128**. Thus, the light source device shown in FIG. **1**K can emit light in multiple locations that correspond to extraction features.

In some embodiments, multiple light source devices are used (e.g., a first light source device coupled with a first light emitting component for a first color and a second light source device coupled with a second light emitting component for a second color). For brevity, such details are omitted herein.

The light source devices shown in FIGS. **1**F-**1**K can be used as described above with respect to FIGS. **1**A-**1**E for determining and/or adjusting an alignment of one or more lenses.

FIGS. **1**L-**1**M are schematic diagrams illustrating a device for providing optical cues for adjusting a distance between an optical element (e.g., lens **130**) and eye **140** in accordance with some embodiments.

FIG. **1**L illustrates that light source device **122-1** emits light **134** (e.g., a green light) and light source device **122-2** emits light **154** (e.g., a red light). Light **134** and light **154**, after lens **130** steers light **134** and light **154**, intersect with each other. The location where light **134** intersects with light **154** corresponds to a preselected eye relief (e.g., a design eye relief that corresponds to a position of an eye, for which device **100** is designed).

FIG. **1**L also illustrates eye positioning devices **184** (e.g., an eyecup, a goggle frame, a cushion coupled with a goggle frame, etc.). In some embodiments, eye positioning device **184** is configured to provide a mechanical support on a region around an eye of a user (e.g., a portion of a supraorbital region and a portion of a infraorbital region, such as an eyebrow region and a cheek region). Eye positioning device **184** is configured to move so that a distance between eye positioning device **184** and lens **130** can be adjusted. For example, eye positioning device **184** is mounted on rail **182**. In some embodiments, eye positioning device **184** is mounted on a thread (e.g., a rotating eyecup). Thus, by moving a position of eye positioning device **184**, a distance between an eye located adjacent to positioning device **184** and lens **130** can be changed (this is sometimes referred to as an adjustment of an eye relief).

In some embodiments, eye positioning device **184** is coupled with a mechanical lock that prevents movement of eye positioning device **184** relative to lens **130** when the mechanical lock is engaged. In some embodiments, eye positioning device **184** is configured to require a force above a certain threshold (e.g., based on mechanical friction) in a particular direction for changing a distance between eye positioning device **184** and lens **130** (e.g., a rotating eyecup).

In FIG. **1**L, light **134** and light **154** do not enter through pupil **150** of a user. Thus, the user can determine that eye **140** is not located at the preselected eye relief (e.g., a distance between lens **130** and eye **140** does not correspond to a preselected distance between lens **130** and eye **140**) based on absence of light **134** and light **154** received through pupil **150**.

FIG. **1**M illustrates that the position of eye positioning device **184** has changed (e.g., the user has turned a rotating eyecup or slid eye positioning device **184** along rail **182**). In FIG. **1**M, both light **134** and light **154** enter through pupil **150** of eye **140**. Thus, the user can determine that eye **140** is located at the preselected eye relief (e.g., the distance between lens **130** and eye **140** corresponds to the preselected distance between lens **130** and eye **140**) based on receiving both light **134** and light **154** through pupil **150**.

Insets shown in FIG. **1**M illustrate the direction of light **134** and light **154**. The inset showing a side view illustrates that light **134** from light source device **122-1** and light **154** from light source device **122-2** are steered by lens **130** so that light **134** intersects with light **154**. The inset showing a front view illustrates that light **134** approaches eye **140** from a location above an optical axis of device **100** toward the optical axis of device **100**, and light **154** approaches eye **140** from a location below the optical axis of device **100** toward the optical axis of device **100**.

FIG. **1**N is similar to FIG. **1**M, except that in FIG. **1**N, light source device **122-3** is used instead of light source device **122-2** shown in FIG. **1**M. Light **156** from light source device **122-3** intersects with light **134**, after light **156** and light **134** pass through lens **130**, to provide a cue indicating a position corresponding to a preselected eye relief.

Insets shown in FIG. **1**N illustrate that light **134** propagates on a first plane (e.g., a vertical plane) and light **156** propagates on a second plane (e.g., a horizontal plane) that is not parallel to the first plane. In some embodiments, the second plane is perpendicular to the first plane as shown in the inset showing a front view.

FIGS. **1**O-**1**P are schematic diagrams illustrating a device for providing optical cues for adjusting a distance between an optical element (e.g., lens **130**) and eye **140** in accordance with some embodiments.

FIG. **1**O is similar to FIG. **1**M, except that light source device **122-1** emits light **134**, **158**, and **162** (e.g., sequentially or concurrently) and light source device **122-2** emits light **154**, **160**, and **164** (e.g., sequentially or concurrently). In some embodiments, light source device **122-1** emits light **134** concurrently with emission of light **154** by light source device **122-2**. In some embodiments, light source device **122-1** emits light **158** concurrently with emission of light **160** by light source device **122-2**. In some embodiments, light source device **122-1** emits light **162** concurrently with emission of light **164** by light source device **122-2**.

Similar to FIG. **1**M, light **134** in FIG. **1**O intersects with light **154** at a position that corresponds to a preselected eye relief. Light **162** intersects with light **164** at a position that does not correspond to the preselected eye relief. Light **158** intersects with light **160** at a position that does not correspond to the preselected eye relief.

Thus, as shown in FIG. **1**P, when light **158** and light **160** both enter through the pupil of eye **140**, the user can determine that eye **140** is not located at the preselected eye relief (e.g., a distance between lens **130** and eye **140** does not correspond to a preselected distance between lens **130** and eye **140**) based on receiving both light **158** and light **160** received through the pupil of eye **140**. In some embodiments, the color and/or the time-dependent intensity pattern of light **158** and light **160** indicate that a distance between lens **130** and eye **140** is greater than the preselected eye relief, which facilitates adjustment and/or correction of the distance between lens **130** and eye **140**. By indicating the direction of the required adjustment, the time required for adjusting the eye relief can be reduced.

FIG. **1**Q is a schematic diagram illustrating a device for providing optical cues for adjusting a distance between an optical element (e.g., lens **130**) and eye **140** in accordance with some embodiments.

FIG. **1**Q is similar to FIG. **1**N, except that light source device **122-1** emits light **158** and light source device **122-3** emits light **168**. Light **158** intersects with light **168** at a position, which provides a cue indicating that the position where light **158** intersects with light **168** does not correspond to the preselected eye relief.

FIG. **1**R illustrates display device **190** in accordance with some embodiments. In some embodiments, display device **190** is configured to be worn on a head of a user (e.g., by having the form of spectacles or eyeglasses, as shown in FIG. **1**R) or to be included as part of a helmet that is to be worn by the user. When display device **190** is configured to be worn on a head of a user or to be included as part of a helmet, display device **190** is called a head-mounted display. Alternatively, display device **190** is configured for placement in proximity of an eye or eyes of the user at a fixed location, without being head-mounted (e.g., display device **190** is mounted in a vehicle, such as a car or an airplane, for placement in front of an eye or eyes of the user).

In some embodiments, display device **190** includes one or more components described below with respect to FIG. **2**. In some embodiments, display device **190** includes additional components not shown in FIG. **2**.

FIG. **2** is a block diagram of system **200** in accordance with some embodiments. The system **200** shown in FIG. **2** includes display device **205** (which corresponds to display device **190** shown in FIG. **1**R), imaging device **235**, and input interface **240** that are each coupled to console **210**. While FIG. **2** shows an example of system **200** including one display device **205**, imaging device **235**, and input interface **240**, in other embodiments, any number of these components may be included in system **200**. For example, there may be multiple display devices **205** each having associated input interface **240** and being monitored by one or more imaging devices **235**, with each display device **205**, input interface **240**, and imaging devices **235** communicating with console **210**. In alternative configurations, different and/or additional components may be included in system **200**. For example, in some embodiments, console **210** is connected via a network (e.g., the Internet) to system **200** or is self-contained as part of display device **205** (e.g., physically located inside display device **205**). In some embodiments, display device **205** is used to create mixed reality by adding in a view of the real surroundings. Thus, display device **205** and system **200** described here can deliver virtual reality, mixed reality, and augmented reality.

In some embodiments, as shown in FIG. **1**R, display device **205** is a head-mounted display that presents media to a user. Examples of media presented by display device **205** include one or more images, video, audio, or some combination thereof. In some embodiments, audio is presented via an external device (e.g., speakers and/or headphones) that receives audio information from display device **205**, console **210**, or both, and presents audio data based on the audio information. In some embodiments, display device **205** immerses a user in a virtual environment.

In some embodiments, display device **205** also acts as an augmented reality (AR) headset. In these embodiments, display device **205** augments views of a physical, real-world environment with computer-generated elements (e.g., images, video, sound, etc.). Moreover, in some embodiments, display device **205** is able to cycle between different types of operation. Thus, display device **205** operate as a virtual reality (VR) device, an AR device, as glasses or some combination thereof (e.g., glasses with no optical correction, glasses optically corrected for the user, sunglasses, or some combination thereof) based on instructions from application engine **255**.

Display device **205** includes electronic display **215**, one or more processors **216**, eye tracking module **217**, adjustment module **218**, one or more locators **220**, one or more position sensors **225**, one or more position cameras **222**, memory **228**, inertial measurement unit (IMU) **230**, or a subset or superset thereof (e.g., display device **205** with electronic display **215**, one or more processors **216**, and memory **228**, without any other listed components). Some embodiments of display device **205** have different modules than those described here. Similarly, the functions can be distributed among the modules in a different manner than is described here.

One or more processors **216** (e.g., processing units or cores) execute instructions stored in memory **228**. Memory **228** includes high-speed random access memory, such as DRAM, SRAM, DDR RAM or other random access solid state memory devices; and may include non-volatile memory, such as one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid state storage devices. Memory **228**, or alternately the non-volatile memory device(s) within memory **228**, includes a non-transitory computer readable storage medium. In some embodiments, memory **228** or the computer readable storage medium of memory **228** stores programs, modules and data structures, and/or instructions for displaying one or more images on electronic display **215**.

Electronic display **215** displays images to the user in accordance with data received from console **210** and/or processor(s) **216**. In various embodiments, electronic display **215** may comprise a single adjustable electronic display element or multiple adjustable electronic displays elements (e.g., a display for each eye of a user).

In some embodiments, the display element includes one or more light emission devices and a corresponding array of emission intensity array. An emission intensity array is an array of electro-optic pixels, opto-electronic pixels, some other array of devices that dynamically adjust the amount of light transmitted by each device, or some combination thereof. These pixels are placed behind one or more lenses. In some embodiments, the emission intensity array is an array of liquid crystal based pixels in an LCD (a Liquid Crystal Display). Examples of the light emission devices include: an organic light emitting diode, an active-matrix organic light-emitting diode, a light emitting diode, some type of device capable of being placed in a flexible display, or some combination thereof. The light emission devices include devices that are capable of generating visible light (e.g., red, green, blue, etc.) used for image generation. The emission intensity array is configured to selectively attenuate individual light emission devices, groups of light emission devices, or some combination thereof. Alternatively, when the light emission devices are configured to selectively attenuate individual emission devices and/or groups of light emission devices, the display element includes an array of such light emission devices without a separate emission intensity array.

One or more lenses direct light from the arrays of light emission devices (optionally through the emission intensity arrays) to locations within each eyebox and ultimately to the back of the user's retina(s). An eyebox is a region that is occupied by an eye of a user located proximity to display device **205** (e.g., a user wearing display device **205**) for viewing images from display device **205**. In some cases, the eyebox is represented as a 10 mm×10 mm square. In some embodiments, the one or more lenses include one or more coatings, such as anti-reflective coatings.

In some embodiments, the display element includes an infrared (IR) detector array that detects IR light that is retro-reflected from the retinas of a viewing user, from the surface of the corneas, lenses of the eyes, or some combination thereof. The IR detector array includes an IR sensor or a plurality of IR sensors that each correspond to a different position of a pupil of the viewing user's eye. In alternate embodiments, other eye tracking systems may also be employed.

Eye tracking module **217** determines locations of each pupil of a user's eyes. In some embodiments, eye tracking module **217** instructs electronic display **215** to illuminate the eyebox with IR light (e.g., via IR emission devices in the display element).

A portion of the emitted IR light will pass through the viewing user's pupil and be retro-reflected from the retina toward the IR detector array, which is used for determining the location of the pupil. Alternatively, the reflection off of the surfaces of the eye is used to also determine location of the pupil. The IR detector array scans for retro-reflection and identifies which IR emission devices are active when retro-reflection is detected. Eye tracking module **217** may use a tracking lookup table and the identified IR emission devices to determine the pupil locations for each eye. The tracking lookup table maps received signals on the IR detector array to locations (corresponding to pupil locations) in each eyebox. In some embodiments, the tracking lookup table is generated via a calibration procedure (e.g., user looks at various known reference points in an image and eye tracking module **217** maps the locations of the user's pupil while looking at the reference points to corresponding signals received on the IR tracking array). As mentioned above, in some embodiments, system **200** may use other eye tracking systems than the embedded IR one described above.

Adjustment module **218** generates an image frame based on the determined locations of the pupils. In some embodiments, this sends a discrete image to the display that will tile subimages together thus a coherent stitched image will appear on the back of the retina. Adjustment module **218** adjusts an output (i.e. the generated image frame) of electronic display **215** based on the detected locations of the pupils. Adjustment module **218** instructs portions of electronic display **215** to pass image light to the determined locations of the pupils. In some embodiments, adjustment module **218** also instructs the electronic display to not pass image light to positions other than the determined locations of the pupils. Adjustment module **218** may, for example, block and/or stop light emission devices whose image light falls outside of the determined pupil locations, allow other light emission devices to emit image light that falls within the determined pupil locations, translate and/or rotate one or more display elements, dynamically adjust curvature and/or refractive power of one or more active lenses in the lens (e.g., microlens) arrays, or some combination thereof.

Optional locators **220** are objects located in specific positions on display device **205** relative to one another and relative to a specific reference point on display device **205**. A locator **220** may be a light emitting diode (LED), a corner cube reflector, a reflective marker, a type of light source that contrasts with an environment in which display device **205** operates, or some combination thereof. In embodiments where locators **220** are active (i.e., an LED or other type of light emitting device), locators **220** may emit light in the visible band (e.g., about 400 nm to 750 nm), in the infrared band (e.g., about 750 nm to 1 mm), in the ultraviolet band (about 100 nm to 400 nm), some other portion of the electromagnetic spectrum, or some combination thereof.

In some embodiments, locators **220** are located beneath an outer surface of display device **205**, which is transparent to the wavelengths of light emitted or reflected by locators **220** or is thin enough to not substantially attenuate the wavelengths of light emitted or reflected by locators **220**. Additionally, in some embodiments, the outer surface or other portions of display device **205** are opaque in the visible band of wavelengths of light. Thus, locators **220** may emit light in the IR band under an outer surface that is transparent in the IR band but opaque in the visible band.

IMU **230** is an electronic device that generates calibration data based on measurement signals received from one or more position sensors **225**. Position sensor **225** generates one or more measurement signals in response to motion of display device **205**. Examples of position sensors **225** include: one or more accelerometers, one or more gyroscopes, one or more magnetometers, another suitable type of sensor that detects motion, a type of sensor used for error correction of IMU **230**, or some combination thereof. Position sensors **225** may be located external to IMU **230**, internal to IMU **230**, or some combination thereof.

Based on the one or more measurement signals from one or more position sensors **225**, IMU **230** generates first calibration data indicating an estimated position of display device **205** relative to an initial position of display device **205**. For example, position sensors **225** include multiple accelerometers to measure translational motion (forward/back, up/down, left/right) and multiple gyroscopes to measure rotational motion (e.g., pitch, yaw, roll). In some embodiments, IMU **230** rapidly samples the measurement signals and calculates the estimated position of display device **205** from the sampled data. For example, IMU **230** integrates the measurement signals received from the accelerometers over time to estimate a velocity vector and integrates the velocity vector over time to determine an estimated position of a reference point on display device **205**. Alternatively, IMU **230** provides the sampled measurement signals to console **210**, which determines the first calibration data. The reference point is a point that may be used to describe the position of display device **205**. While the reference point may generally be defined as a point in space; however, in practice the reference point is defined as a point within display device **205** (e.g., a center of IMU **230**).

In some embodiments, IMU **230** receives one or more calibration parameters from console **210**. As further discussed below, the one or more calibration parameters are used to maintain tracking of display device **205**. Based on a received calibration parameter, IMU **230** may adjust one or more IMU parameters (e.g., sample rate). In some embodiments, certain calibration parameters cause IMU **230** to update an initial position of the reference point so it corresponds to a next calibrated position of the reference point. Updating the initial position of the reference point as the next calibrated position of the reference point helps reduce accumulated error associated with the determined estimated position. The accumulated error, also referred to as drift error, causes the estimated position of the reference point to "drift" away from the actual position of the reference point over time.

Imaging device **235** generates calibration data in accordance with calibration parameters received from console **210**. Calibration data includes one or more images showing observed positions of locators **220** that are detectable by imaging device **235**. In some embodiments, imaging device **235** includes one or more still cameras, one or more video cameras, any other device capable of capturing images including one or more locators **220**, or some combination thereof. Additionally, imaging device **235** may include one or more filters (e.g., used to increase signal to noise ratio). Imaging device **235** is configured to optionally detect light emitted or reflected from locators **220** in a field of view of imaging device **235**. In embodiments where locators **220** include passive elements (e.g., a retroreflector), imaging device **235** may include a light source that illuminates some or all of locators **220**, which retro-reflect the light towards the light source in imaging device **235**. Second calibration data is communicated from imaging device **235** to console **210**, and imaging device **235** receives one or more calibration parameters from console **210** to adjust one or more imaging parameters (e.g., focal length, focus, frame rate, ISO, sensor temperature, shutter speed, aperture, etc.).

Input interface **240** is a device that allows a user to send action requests to console **210**. An action request is a request to perform a particular action. For example, an action request may be to start or end an application or to perform a particular action within the application. Input interface **240** may include one or more input devices. Example input devices include: a keyboard, a mouse, a game controller, data from brain signals, data from other parts of the human body, or any other suitable device for receiving action requests and communicating the received action requests to console **210**. An action request received by input interface **240** is communicated to console **210**, which performs an action corresponding to the action request. In some embodiments, input interface **240** may provide haptic feedback to the user in accordance with instructions received from console **210**. For example, haptic feedback is provided when an action request is received, or console **210** communicates instructions to input interface **240** causing input interface **240** to generate haptic feedback when console **210** performs an action.

Console **210** provides media to display device **205** for presentation to the user in accordance with information received from one or more of: imaging device **235**, display device **205**, and input interface **240**. In the example shown in FIG. **2**, console **210** includes application store **245**, tracking module **250**, and application engine **255**. Some embodiments of console **210** have different modules than those described in conjunction with FIG. **2**. Similarly, the functions further described below may be distributed among components of console **210** in a different manner than is described here.

When application store **245** is included in console **210**, application store **245** stores one or more applications for execution by console **210**. An application is a group of instructions, that when executed by a processor, is used for generating content for presentation to the user. Content generated by the processor based on an application may be in response to inputs received from the user via movement of display device **205** or input interface **240**. Examples of applications include: gaming applications, conferencing applications, video playback application, or other suitable applications.

When tracking module **250** is included in console **210**, tracking module **250** calibrates system **200** using one or more calibration parameters and may adjust one or more calibration parameters to reduce error in determination of the position of display device **205**. For example, tracking module **250** adjusts the focus of imaging device **235** to obtain a more accurate position for observed locators on display device **205**. Moreover, calibration performed by tracking module **250** also accounts for information received from IMU **230**. Additionally, if tracking of display device **205** is lost (e.g., imaging device **235** loses line of sight of at least a threshold number of locators **220**), tracking module **250** re-calibrates some or all of system **200**.

In some embodiments, tracking module **250** tracks movements of display device **205** using second calibration data from imaging device **235**. For example, tracking module **250** determines positions of a reference point of display device **205** using observed locators from the second calibration data and a model of display device **205**. In some embodiments, tracking module **250** also determines positions of a reference point of display device **205** using position information from the first calibration data. Additionally, in some embodiments, tracking module **250** may use portions of the first calibration data, the second calibration data, or some combination thereof, to predict a future location of display device **205**. Tracking module **250** provides the estimated or predicted future position of display device **205** to application engine **255**.

Application engine **255** executes applications within system **200** and receives position information, acceleration information, velocity information, predicted future positions, or some combination thereof of display device **205** from tracking module **250**. Based on the received information, application engine **255** determines content to provide to display device **205** for presentation to the user. For example, if the received information indicates that the user has looked to the left, application engine **255** generates content for display device **205** that mirrors the user's movement in a virtual environment. Additionally, application engine **255** performs an action within an application executing on console **210** in response to an action request received from input interface **240** and provides feedback to the user that the action was performed. The provided feedback may be visual or audible feedback via display device **205** or haptic feedback via input interface **240**.

In light of these principles, we now turn to certain embodiments.

In accordance with some embodiments, a device includes a first light source device (e.g., light source device **122-1** in FIG. **1**B) configured to transmit a first light (e.g., first light **132-1**) in a first direction and a second light (e.g., second light **132-2**) in a second direction that is distinct from the first direction. The device also includes a first set of one or more lenses (e.g., lens **130-1** in FIG. **1**B) configured for directing the first light and the second light from the first light source device toward a first eye of a user. The first light is spatially offset from the second light (e.g., first light **132-1** is spatially offset from second light **134-1** as shown in FIG. **1**B). One or more of the first light and the second light provide a cue for adjusting a location (e.g., a lateral location) of the first set of one or more lenses.

In some embodiments, the first light indicates that an eye receiving the first light is offset from a center of the first set of one or more lenses (e.g., as shown in FIG. **1**D, when eye **140-1** receives first light **132-1**, this indicates that eye **140-1** is offset from a lateral position of a center of lens **130-1**). The second light indicates that an eye receiving the second light is aligned with the center of the first set of one or more lenses (e.g., as shown in FIG. **1**B, when eye **140-1** receives second light **134-1**, this indicates that eye **140-1** is aligned with the lateral position of the center of lens **130-1**).

In some embodiments, the first light directed to the first eye is parallel to the second light directed to the first eye (e.g., in FIG. **1**B, first light **132-1** is parallel to second light **134-1** after passing through lens **130-1**).

In some embodiments, the first light source device is further configured to transmit a third light in a third direction that is distinct from the first direction and the second direction; and the first set of one or more lenses is further configured for directing the third light toward the first eye (e.g., in FIG. **1**B, third light **136-1**). The third light is spatially offset from the first light and the second light.

In some embodiments, the first light has a first color (e.g., red), and the second light has a second color (e.g., green) that is distinct from the first color. The first light source device includes a light emitting component configured to provide a broadband light that includes the first light of the first color and the second light of the second color; and an optical grating (e.g., optical grating **148** in FIG. **1**H) configured to disperse the broadband light from the light emitting component, including directing the first light of the first color in the first direction and the second light of the second color in the second direction.

In some embodiments, the first light has a first color (e.g., red), and the second light has a second color (e.g., green) that is distinct from the first color. the first light source device includes a light emitting component configured to provide a broadband light that includes the first light of the first color and the second light of the second color; and a plurality of dichroic mirrors (e.g., set **152** of dichroic mirrors in FIG. **1**I), including a first dichroic mirror and a second dichroic mirror. The first dichroic mirror is configured to reflect the first light of the first color in the first direction and the second dichroic mirror is configured to reflect the second light of the second color in the second direction.

In some embodiments, the first light source device includes a first light emitting component (e.g., first light emitting component **142-1** in FIG. **1**F) configured to provide the first light and a second light emitting component (e.g., second light emitting component **142-2** in FIG. **1**F) configured to provide the second light.

In some embodiments, the first light has a first color (e.g., red), and the second light has a second color (e.g., green) that is distinct from the first color.

In some embodiments, the first light has a first time-dependent intensity pattern (e.g., a first pulsing frequency, a first duty cycle, a first interval, etc.) and the second light has a second time-dependent intensity pattern (e.g., a second pulsing frequency, a second duty cycle, a second interval, etc.). In some embodiments, the second time-dependent intensity pattern is distinct from the first time-dependent intensity pattern.

In some embodiments, the first light emitting component is configured to provide the first light in multiple directions, and the second light emitting component is configured to provide the second light in multiple directions (e.g., FIG. **1**F). The first light source device also includes one or more lenses (e.g., lens **144** in FIG. **1**F). The first light emitting component and the second light emitting component are positioned (e.g., on a focal plane of the one or more lenses) with a lateral offset so that the first light provided by the first light emitting component is directed to the first direction and the second light provided by the second light emitting component is directed to the second direction.

In some embodiments, the first light source device also includes a barrier having an opening (e.g., barrier **146** with a pinhole or a slit, as shown in FIG. **1**G) configured to transmit the first light from the first light emitting component in the first direction and the second light from the second light emitting component in the second direction. In some embodiments, the first light emitting component is configured to provide the first light in multiple directions, and the second light emitting component is configured to provide the second light in multiple directions.

In some embodiments, the device includes a second light source device (e.g., second light source device **122-1** in FIG. **1**B) configured to transmit a fourth light (e.g., fourth light **132-2** in FIG. **1**B) in a fourth direction and a fifth light (e.g., fifth light **134-2** in FIG. **1**B) distinct from the fourth light in a fifth direction that is distinct from the fourth direction. The second light source device is distinct from the first light source device. The device also includes a second set of one or more lenses (e.g., lens **130-2** in FIG. **1**B) configured for directing the fourth light and the fifth light from the second light source device toward a second eye of the user. The fourth light is spatially offset from the fifth light. One or more of the fourth light and the fifth light provide a cue for adjusting a location (e.g., a lateral location) of the second set of one or more lenses.

In some embodiments, the second light source device is further configured to transmit a sixth light (e.g., sixth light **136-2** in FIG. **1**B) in a sixth direction that is distinct from the fourth direction and the fifth direction. The second set of one or more lenses is further configured for directing the sixth light toward the second eye. The sixth light is spatially offset from the fourth light and the fifth light.

In some embodiments, the device also includes one or more display screens (e.g., display screens **110-1** and/or **110-2**) configured to project one or more images through the first set of one or more lenses.

In some embodiments, the device is a head-mounted display device (e.g., FIG. **1**R).

In accordance with some embodiments, a method includes transmitting a first light (e.g., first light **132-1** in FIG. **1**B) in a first direction and a second light (e.g., second light **134-1** in FIG. **1**B) that is distinct from the first light in a second direction that is distinct from the first direction; and transmitting the first light and the second light through a first set of one or more lenses and directing the first light and the second light toward a first eye of a user (e.g., FIG. **1**B). The first light is spatially offset from the second light and one or more of the first light and the second light provide a cue for adjusting a location of the first set of one or more lenses.

In some embodiments, the method also includes, in conjunction with transmitting the first light and the second light through the first set of one or more lenses (e.g., concurrently with transmitting the first light and the second light through the first set of one or more lenses), transmitting a third light that is distinct and spatially offset from the first light and the second light.

In some embodiments, the method also includes transmitting a fourth light (e.g., fourth light **132-2** in FIG. **1**B) in a fourth direction and a fifth light (e.g., fifth light **134-2** in FIG. **1**B) that is distinct form the fourth light in a fifth direction that is distinct from the fourth direction; and transmitting the fourth light and the fifth light through a second set of one or more lenses that is distinct from the first set of one or more lenses and directing the fourth light and the fifth light toward a second eye of the user. The fourth light is spatially offset from the fifth light and one or more of the fourth light and the fifth light provide a cue for adjusting a location of the second set of one or more lenses.

In some embodiments, the method also includes, in conjunction with transmitting the first light and the second light through the first set of one or more lenses, transmitting a reference light from one or more display screens through the first set of one or more lenses (e.g., reference light **138**). In some embodiments, the reference light has a color and/or a time-dependent intensity pattern of the second light. Thus, the reference light can assist with a determination whether the second light is received by an eye. For example, a color of the reference light and a color of light from a light source device are compared to determine whether the color of the light from the light source device matches the color of the reference light. If the color of the light from the light source device matches the color of the reference light, the lens is aligned with the eye. If the color of the light from the light source device does not match the color of the reference light, the lens is not aligned with the eye. In another example, a pulsing frequency of the reference light and a pulsing frequency of light from a light source device are compared to determine whether the pulsing frequency of the light from the light source device matches the pulsing frequency of the reference light. If the pulsing frequency of the light from the light source device matches the pulsing frequency of the reference light, the lens is aligned with the eye. If the pulsing frequency of the light from the light source device does not match the pulsing frequency of the reference light, the lens is not aligned with the eye.

In accordance with some embodiments, a method includes receiving a portion of a bundle of light that includes a first light and a second light that is distinct from the first light and laterally offset from the first light (e.g., FIG. **1**B). The method also includes, in accordance with a determination that the received portion of the bundle of light corresponds to the first light, moving the first set of one or more lenses. For example, when the received portion of the bundle of light has a first color (e.g., in FIG. **1**D, the received portion of the bundle of light has a red color, which indicates that lens **130-1** needs to be moved toward a left side to align with eye **140-1**), the first set of one or more lenses is moved toward the left side.

In some embodiments, the method further includes continuing to monitor the color of a light received by an eye and adjust a lateral position of the lens (or continuing to monitor the color of a light received by each eye and adjust lateral positions of the first lens and the second lens) until the first lens is accurately positioned (or both the first lens and the second lens are accurately positioned). In some embodiments, an accurate positioning of a lens is indicated by whether a particular light (e.g., having a particular color, such as green, and/or having a particular time-dependent intensity pattern, such as a pulsing frequency, a duty cycle, and/or an interval) is delivered toward a pupil of an eye.

In accordance with some embodiments, a device includes a first light source device configured to transmit a first light in a first direction (e.g., light source device **122-1** in FIG. **1**L is configured to emit light **134**) and a second light source device configured to transmit a second light in a second direction (e.g., light source device **122-2** in FIG. **1**L is configured to emit light **154**). In some embodiments, the second direction is distinct from the first direction. The device also includes a first set of one or more lenses (e.g., lens **130**) configured for directing, toward a first eye of a user (e.g., a left eye), the first light from the first light source device and the second light from the second light source device so that the first light intersects with the second light at a first location (e.g., in FIG. **1**L, light **134** and light **154** intersect with each other). One or more of the first light and the second light provide a cue for adjusting a location of the first set of one or more lenses relative to the first eye of the user (e.g., adjusting a position of the first eye relative to the first set of one or more lenses or adjusting a position of one or more lenses of the first set of one or more lenses relative to the first eye). For example, as shown in FIG. **1**L, the user can determine that eye **140** is not located at a position that corresponds to the design eye relief of device **100** based on not receiving both light **134** and light **154** through pupil **150** of eye **140**.

In some embodiments, the first light has a first set of properties. The second light has a second set of properties that is distinct from the first set of properties. Each of the first set of properties and the second set of properties is characterized by a color and/or a time-dependent intensity pattern. For example, the first light has a first color and the second light has a second color that is distinct from the first color. In another example, the first light has a first time-dependent intensity pattern (e.g., a pulsing frequency, a duty cycle, and/or an interval) and the second light has a second time-dependent intensity pattern that is distinct from the first time-dependent intensity pattern (e.g., the second light has a pulsing frequency that is distinct from a pulsing frequency of the first light). In some embodiments, the first light has a time-independent intensity pattern (e.g., the intensity of the first light does not change over time), and the second light has a time-dependent intensity pattern (e.g., the intensity of the second light changes over time). In some embodiments, the first light has a time-dependent intensity pattern, and the second light has a time-independent intensity pattern.

In some embodiments, the first light source device is configured to transmit a third light (e.g., light **158** in FIG. **1**O) in a third direction that is distinct from at least one of the first direction and the second direction. The second light source device is configured to transmit a fourth light (e.g., light **160** in FIG. **1**O) in a fourth direction that is distinct from at least one of the first direction and the second direction. In some embodiments, the fourth direction is distinct from the third direction. The first set of one or more lenses is configured for directing, toward the first eye of the user, the third light from the first light source device and the fourth light from the second light source device so that the third light intersects with the fourth light at a second location that is distinct from the first location (e.g., as shown in the inset of FIG. **1**O, light **158** intersects with light **160** at a location that is distinct from a location where light **134** intersects with light **154**).

In some embodiments, a path of the first light before passing through the first set of one or more lenses and a path of the first light after passing through the first set of one or more lenses define a first plane. A path of the second light before passing through the first set of one or more lenses and a path of the second light after passing through the first set of one or more lenses define a second plane. The second plane is substantially parallel to the first plane (e.g., the angle between the first plane and the second plane is 20 degrees or less). A path of the third light before passing through the first set of one or more lenses and a path of the third light after passing through the first set of one or more lenses define a third plane. The third plane is substantially parallel to the first plane (e.g., the angle between the first plane and the third plane is 20 degrees or less). For example, in FIG. **1**O, the plane defined by light **134** before and after passing through lens **130** is parallel to the plane defined by light **154** before and after passing through lens **130** and the plane defined by light **158** before and after passing through lens **130**.

In some embodiments, a path of the first light before passing through the first set of one or more lenses and a path of the first light after passing through the first set of one or more lenses define a first plane. A path of the second light before passing through the first set of one or more lenses and a path of the second light after passing through the first set of one or more lenses define a second plane. The second plane is substantially parallel to the first plane (e.g., the angle between the first plane and the second plane is 20 degrees or less). A path of the third light before passing through the first set of one or more lenses and a path of the third light after passing through the first set of one or more lenses define a third plane. The third plane is substantially perpendicular to the first plane (e.g., the angle between the first plane and the third plane is between 70 degrees and 110 degrees).

In some embodiments, the first light source device is further configured to transmit a fifth light (e.g., light **162** in FIG. **1**O) in a fifth direction that is distinct from the first direction and the third direction. The second light source device is further configured to transmit a sixth light (e.g., light **164** in FIG. **1**O) in a sixth direction that is distinct from the second direction and the fourth direction. The first set of one or more lenses is further configured for directing the fifth light and the sixth light toward the first eye so that the fifth light intersects with the sixth light at a third location that is distinct from the first location and the second location (e.g., as shown in the inset of FIG. **1**O, light **162** intersects with light **164** at a location that is distinct from a location where light **134** intersects with light **154** and a location where light **158** intersects with light **160**).

In some embodiments, the first light has a first set of properties. The second light has a second set of properties that is distinct from the first set of properties. The third light has a third set of properties that is distinct from the first set of properties and the second set of properties. The fourth light has a fourth set of properties that is distinct from the first set of properties, the second set of properties, and the third set of properties. Each of the first set of properties, the second set of properties, the third set of properties, and the fourth set of properties is characterized by a color and/or a time-dependent intensity pattern. For example, the first light can be distinguished from the second light, the third light, and the fourth light based on the color and/or the time-dependent intensity pattern; the second light can be distinguished from the third light and the fourth light based on the color and/or the time-dependent intensity pattern; and the third light can be distinguished from the fourth light based on the color and/or the time-dependent intensity pattern.

In some embodiments, the first light source device includes a first light guide with one or more extraction features (e.g., light guide **126-1** in FIG. **1**J with extraction feature **128**). The second light source device includes a second light guide with one or more extraction features (e.g., another light guide that has a structure corresponding to light guide **126-1**). The second light guide is distinct and separate from the first light guide. Each light guide of the first light guide and the second light guide is optically coupled with a respective light emitting component (e.g., the first light guide is coupled with a green LED, and the second light guide is coupled with a red LED).

In some embodiments, the device includes an electronic display (e.g., light emission device array **110**). The first light guide and the second light guide are located between the electronic display and the first set of one or more lenses (e.g., as shown in FIG. **1**J, the first light guide can be placed over light emission device array **110** so that the first light guide is located between light emission device array **110** and lens **130**).

In some embodiments, the device includes one or more input devices configured for receiving a user input requesting an adjustment of a distance between the first eye and a lens of the first set of one or more lenses (e.g., adjusting an eye relief). In some embodiments, eye positioning device **184** is coupled with a mechanical positioning device, such as a linear motor, or a rotary motor coupled with a rail or a rack and pinion, and the device is configured to move eye positioning device **184** in accordance with the user input requesting an adjustment of the eye relief (e.g., a user pressing a button initiate movement of eye positioning device **184**). In some embodiments, the one or more input devices comprise a rotating eyecup.

In some embodiments, the device includes a third light source device that is distinct from the first light source device and the second light source device and configured to transmit a seventh light in a seventh direction. The device also includes a fourth light source device that is distinct from the first light source device and the second light source device and configured to transmit an eighth light distinct from the seventh light in an eighth direction. In some embodiments, the eighth direction is distinct from the seventh direction. The device further includes a second set of one or more lenses configured for directing, toward a second eye of a user, the seventh light from the third light source device and the eighth light from the fourth light source device so that the seventh light intersects with the eighth light at a third location that is distinct from the first location and the second location. For example, the first light source device and the second light source device are used for adjusting an eye relief for a left eye, and the third light source device and the fourth light source device are used for adjusting an eye relief for a right eye. The third location corresponds to a design eye relief for the right eye. In some embodiments, the first location and the third location correspond to a same eye relief (e.g., the device is configured for a same eye relief for both left and right eyes).

In some embodiments, the third light source device is configured to transmit a ninth light in a ninth direction that is distinct from at least one of the seventh direction and the eighth direction. The fourth light source device is configured to transmit a tenth light in a tenth direction that is distinct from at least one of the seventh direction and the eighth direction. In some embodiments, the tenth direction is distinct from the ninth direction. The second set of one or more lenses is configured for directing toward the second eye of the user, the ninth light from the third light source device and the tenth light from the fourth light source device so that the ninth light intersects with the tenth light at a fourth location that is distinct from the first location, the second location, and the third location. For example, the fourth location does not correspond to a design eye relief for the right eye.

In some embodiments, a combination of the first light and the second light indicates that the first eye receiving both the first light and the second light is at a predefined eye relief of the device (e.g., FIG. **1**M).

In some embodiments, the first light indicates that the first eye receiving the first light is aligned with a center of the first set of one or more lenses in one of a horizontal direction and a vertical direction. For example, in FIG. **1**N, light **134** indicates that eye **140** is aligned with lens **130** in a horizontal direction (e.g., a center of lens **130** and a center of eye **140** are horizontally aligned, although they may be offset vertically). The second light indicates that the first eye receiving the second light is aligned with a center of the first set of one or more lenses in the other of a horizontal direction or a vertical direction. For example, in FIG. **1**N, light **156** indicates that eye **140** is aligned with lens **130** in a vertical direction (e.g., a center of lens **130** and a center of eye **140** are vertically aligned, although they may be offset horizontally).

In some embodiments, the device includes one or more display screens (e.g., light emission device array **110**) configured to project one or more images through the first set of one or more lenses. In some embodiments, the device includes a single display screen for both left and right eyes. In some embodiments, the device includes separate display screens for the left and right eyes (e.g., a first display screen for the left eye and a second display screen that is distinct and separate from the first display screen for the right eye).

In some embodiments, the device is a head-mounted display device (e.g., FIG. **1**R).

In some embodiments, the device includes an adjustable mount configured to holding at least one lens of the first set of one or more lenses and move a position of the at least one lens of the first set of one or more lenses. For example, the mount is slidably coupled with one or more rails. This allows adjusting a lateral position of the at least one lens of the first set of one or more lenses (e.g., FIGS. **1**C-**1**E). In some embodiments, the device includes a first adjustable mount configured for holding at least one lens of the first set of one or more lenses and moving a position of the at least one lens of the first set of one or more lenses, and a second adjustable mount configured for holding at least one lens of the second set of one or more lenses and moving a position of the at least one lens of the second set of one or more lenses. In some embodiments, the first adjustable mount is mechanically coupled with the second adjustable mount (e.g., the at least one lens of the first set of one or more lenses and the at least one lens of the second set of one or more lenses move concurrently toward a nasal region or toward respective temporal regions).

In some embodiments, the device includes a light source device configured to transmit, in conjunction with the first light source device transmitting the first light and the second light source device transmitting the second light, a reference light through the first set of one or more lenses (e.g., pixel **124** emits reference light **138**).

In accordance with some embodiments, a method includes transmitting, from a first light source device, a first light in a first direction (e.g., light **134** from light source device **122-1** shown in FIG. **1**L); transmitting, from a second light source device, a second light that is distinct from the first light in a second direction (e.g., light **154** from light source device **122-2** shown in FIG. **1**L). In some embodiments, the second direction is distinct from the first direction. The method also includes transmitting the first light and the second light through a first set of one or more lenses and directing the first light and the second light toward a first eye of a user (e.g., a left eye of the user). In some embodiments, the first light and the second light are transmitted concurrently. However, the first light and the second light need not be transmitted concurrently. For example, the first light and the second light are transmitted sequentially. In another example, the first light and the second light are transmitted alternatingly so that they are not transmitted concurrently.

In accordance with some embodiments, a method includes receiving a portion of a light beam that includes a first light from a first light source device (e.g., light **134** from light source device **122-1** as shown in FIG. **1**L) and a second light that is distinct from the first light from a second light source device (e.g., light **154** from light source device **122-2** as shown in FIG. **1**L). The first light and the second light have been transmitted through a first set of one or more lenses. After transmitting through the first set of one or more lenses, the first light is configured to intersect with the second light. The method also includes, in accordance with a determination that the received portion of the light beam does not include both the first light and the second light, adjusting a distance between an eye and a lens of the first set of one or more lenses (e.g., adjusting an eye relief). For example, when eye **140** does not receive, through pupil **150**, both light **134** and light **154** as shown in FIG. **1**L, the user can determine that eye **140** is not located at a position that corresponds to a design eye relief, and initiate adjusting the distance between eye **140** and lens **130** by rotating an eyecup, sliding eye positioning device **184**, activating an actuator, such as a motor, etc.

In some embodiments, the method includes, in accordance with a determination that the received portion of the light beam includes both the first light and the second light, ceasing to adjust the distance between the eye and the lens of the first set of one or more lenses (e.g., when eye **140** receives, through pupil **150**, both light **134** and light **154** as shown in FIG. **1**M, the user can determine that eye **140** is located at a position that corresponds to a design eye relief, and stops adjusting the distance between eye **140** and lens **130**).

Although some of various drawings illustrate a number of logical stages in a particular order, stages which are not order dependent may be reordered and other stages may be combined or broken out. While some reordering or other groupings are specifically mentioned, others will be apparent to those of ordinary skill in the art, so the ordering and groupings presented herein are not an exhaustive list of alternatives. Moreover, it should be recognized that the stages could be implemented in hardware, firmware, software or any combination thereof.

The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the scope of the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings.

For example, in accordance with some embodiments, a device includes a first light source device configured to transmit a first light in a first direction (e.g., and not in a second direction that is distinct from the first direction). In some embodiments, the first light source device includes barrier **146** with an opening (e.g., a pinhole or a slit) and light emitting component **142-2**, but not light emitting components **142-1** and **142-3** shown in FIG. **1**G. In some embodiments, the first light source device includes lens **144** (e.g., a cylinder lens) and light emitting component **142-2**, but not light emitting components **142-1** and **142-3** shown in FIG. **1**F. The device also includes a first set of one or more lenses configured for directing the first light toward a first eye of a user. The first light is spatially restricted (e.g., a beam of the first light directed toward the first eye of the user has a width or a diameter less than 5 mm, 4 mm, 3 mm, 2 mm, or 1 mm). The first light provides a cue for adjusting a location of the first set of one or more lenses. In some embodiments, the first light is transmitted through a lateral center of the first set of one or more lenses. Thus, when a user sees the first light with the first eye, this indicates that the first set of one or more lenses is aligned with the first eye.

When the user does not see the first light with the first eye, this indicates that the first set of one or more lenses is not aligned with the first eye.

In accordance with some embodiments, a method includes transmitting a first light in a first direction, and transmitting the first light through a first set of one or more lenses and directing the first light toward a first eye of a user. The first light is spatially restricted. The first light provides a cue for adjusting a location of the first set of one or more lenses.

In accordance with some embodiments, a method includes receiving at least a portion of a bundle of a first light that is spatially restricted. The method also includes, in accordance with a determination that the at least a portion of a bundle of the first light is received, moving the first set of one or more lenses (e.g., based on an intensity of the received portion of the bundle of the first light so that a center of the bundle of the first light is received by a first eye of a user). Alternatively, the method includes, in accordance with a determination that no portion of the bundle of the first light is received, moving the first set of one or more lenses (because the first set of one or more lenses is not aligned with the first eye of the user).

The embodiments described herein were chosen in order to best explain the principles underlying the claims and their practical applications, to thereby enable others skilled in the art to best use the embodiments with various modifications as are suited to the particular uses contemplated.

What is claimed is:

1. A device, comprising:

a first light source device configured to provide a first light in a first direction and a second light in a second direction that is distinct from the first direction;

a second light source device configured to provide a third light in a third direction that is distinct from the first direction and a fourth light in a fourth direction that is distinct from the second direction; and

a first set of one or more lenses configured for directing, toward a first eye of a user, the first light and the second light from the first light source device and the third light and the fourth light from the second light source device so that the first light intersects with the third light at a first location at a first distance from the first set of one or more lenses and the second light intersects with the fourth light at a second location at a second distance, distinct from the first distance, from the first set of one or more lenses, wherein:

the first light, the second light, the third light, and the fourth light are distinguishable from one another based on at least one of: a color and a time-dependent intensity pattern;

the first set of one or more lenses defines a first optical axis;

the first light source device includes at least two light sources and an optical element optically coupled with at least the two light sources for steering the first light in the first direction and steering the second light in the second direction; and

the first light source device, including at least the two light sources and the optical element, is positioned away from the first optical axis.

2. The device of claim **1**, wherein:

the first light has a first set of properties;

the third light has a second set of properties that is distinct from the first set of properties; and

each of the first set of properties and the second set of properties is characterized by a color and/or a time-dependent intensity pattern.

3. The device of claim **1**, wherein:

a path of the first light before passing through the first set of one or more lenses and a path of the first light after passing through the first set of one or more lenses define a first plane;

a path of the third light before passing through the first set of one or more lenses and a path of the third light after passing through the first set of one or more lenses define a second plane;

the second plane is substantially parallel to the first plane;

a path of the second light before passing through the first set of one or more lenses and a path of the second light after passing through the first set of one or more lenses define a third plane; and

the third plane is substantially parallel or substantially perpendicular to the first plane.

4. The device of claim **1**, wherein:

the first light source device is further configured to provide a fifth light in a fifth direction that is distinct from the first direction and the second direction;

the second light source device is further configured to provide a sixth light in a sixth direction that is distinct from the third direction and the fourth direction; and

the first set of one or more lenses is further configured for directing the fifth light and the sixth light toward the first eye so that the fifth light intersects with the sixth light at a third location that is distinct from the first location and the second location.

5. The device of claim **1**, further comprising:

an eye positioning device configured for adjusting a distance between the first eye and a lens of the first set of one or more lenses.

6. The device of claim **1**, wherein:

a combination of the first light and the third light indicates that the first eye receiving both the first light and the third light is at a predefined eye relief of the device.

7. The device of claim **1**, wherein:

the first light indicates that the first eye receiving the first light is aligned with a center of the first set of one or more lenses in one of a horizontal direction and a vertical direction; and

the third light indicates that the first eye receiving the third light is aligned with a center of the first set of one or more lenses in the other of a horizontal direction or a vertical direction.

8. The device of claim **1**, further comprising:

a light source device configured to transmit, in conjunction with the first light source device providing the first light and the second light source device providing the third light, a reference light through the first set of one or more lenses.

9. The device of claim **1**, wherein the optical element is further configured to:

steer the first light in the first direction without steering the first light in the second direction; and

steer the second light in the second direction without steering the second light in the first direction.

10. The device of claim **1**, wherein the optical element is selected from a group consisting of: a lens, a barrier with a pinhole, an optical grating, a set of dichroic mirrors, and a light guide.

11. The device of claim **1**, wherein:

the second light source device is distinct and separate from the first light source device and includes at least two light sources and an optical element optically coupled with at least the two light sources of the second light source device for steering light from at least the two light sources of the second light source device; and

the second light source device is positioned away from the first optical axis so that the first optical axis does not intersect at least the two light sources and the optical element of the second light source device.

12. The device of claim **1**, wherein:

the second light source device includes a light guide with one or more extraction features.

13. The device of claim **12**, further comprising:

an electronic display, wherein the light guide is located between the electronic display and the first set of one or more lenses.

14. The device of claim **1**, further comprising:

a third light source device that is distinct from the first light source device and the second light source device and configured to provide a seventh light in a seventh direction;

a fourth light source device that is distinct from the first light source device and the second light source device and configured to provide an eighth light distinct from the seventh light in an eighth direction; and

a second set of one or more lenses configured for directing, toward a second eye of a user, the seventh light from the third light source device and the eighth light from the fourth light source device so that the seventh light intersects with the eighth light at a third location that is distinct from the first location and the second location.

15. The device of claim **14**, wherein:

the third light source device is configured to provide a ninth light in a ninth direction that is distinct from at least one of the seventh direction and the eighth direction;

the fourth light source device is configured to provide a tenth light in a tenth direction that is distinct from at least one of the seventh direction and the eighth direction; and

the second set of one or more lenses is configured for directing toward the second eye of the user, the ninth light from the third light source device and the tenth light from the fourth light source device so that the ninth light intersects with the tenth light at a fourth location that is distinct from the first location, the second location, and the third location.

16. The device of claim **1**, wherein the device is a head-mounted display device.

17. The device of claim **16**, further comprising:

an adjustable mount configured to holding at least one lens of the first set of one or more lenses and move a position of the at least one lens of the first set of one or more lenses.

18. A method, comprising:

providing, from the first light source device of the device of claim **1**, the first light in the first direction and the second light in the second direction;

providing, from the second light source device, the third light that is distinct from the first light in the third direction and the fourth light in the fourth direction;

transmitting the first light, the second light, the third light, and the fourth light through the first set of one or more lenses and directing the first light, the second light, the third light, and the fourth light toward the first eye of the user; and

steering, with the optical element, the first light in the first direction and the second light in the second direction.

19. The method of claim **18**, comprising:

receiving a portion of a light beam that includes the first light from the first light source device and the third light that is distinct from the first light from the second light source device, wherein:

the first light and the second light have been transmitted through the first set of one or more lenses; and

after transmitting through the first set of one or more lenses, the first light is configured to intersect with the second light; and

in accordance with a determination that the received portion of the light beam does not include both the first light and the third light, adjusting a distance between the first eye of the user and a lens of the first set of one or more lenses.

20. A device, comprising:

a first light source device configured to provide a first light in a first direction and a second light in a second direction that is distinct from the first direction;

a second light source device configured to provide a third light in a third direction that is distinct from the first direction and a fourth light in a fourth direction that is distinct from the second direction; and

a first set of one or more lenses configured for directing, toward a first eye of a user, the first light and the second light from the first light source device and the third light and the fourth light from the second light source device so that the first light intersects with the third light at a first location at a first distance from the first set of one or more lenses and the second light intersects with the fourth light at a second location at a second distance, distinct from the first distance, from the first set of one or more lenses, wherein:

the first light, the second light, the third light, and the fourth light are distinguishable from one another based on at least one of: a color and a time-dependent intensity pattern; and

the first light source device is configured to provide the first light in the first direction and the second light in the second direction without providing the first light in the second direction and without providing the second light in the first direction.

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